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THE USE OF AIR FORCE FIELD MAINTENANCE DATA FOR R AND M ASSESSM--ETC(U)

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RADC-TR-79-103
In-House Report
April 1979

THE USE OF AIR FORCE FIELD MAINTENANCE DATA FOR R&M ASSESSMENTS OF GROUND ELECTRONIC SYSTEMS

Eugene Fiorentino

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) RADC-TR-79-103	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) THE USE OF AIR FORCE FIELD MAINTENANCE DATA FOR R&M ASSESSMENTS OF GROUND ELECTRONIC SYSTEMS. and		5. TYPE OF REPORT & PERIOD COVERED In-House Report July 1975 - August 1978
		6. PERFORMING ORG. REPORT NUMBER N/A
7. AUTHOR(s) (10) Eugene Fiorentino		8. CONTRACT OR GRANT NUMBER(s) N/A
9. PERFORMING ORGANIZATION NAME AND ADDRESS Rome Air Development Center (RBRT) Griffiss AFB NY 13441		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62702F (17) 02 (16) 23380213
11. CONTROLLING OFFICE NAME AND ADDRESS Rome Air Development Center (RBRT) Griffiss AFB NY 13441		12. REPORT DATE (11) April 1979
		13. NUMBER OF PAGES 103
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Same 309 050		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same (9) Technical rept. Jul 75-Aug 78,

18. SUPPLEMENTARY NOTES

None (12) 122p.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Reliability
Maintainability
Statistical Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of a study on the use of Air Force field maintenance data for the reliability and maintainability assessment of operational ground electronic equipments. A currently operational relatively complex ground electronic equipment was used as a study vehicle. Comparisons are made between the R&M estimates derived from the field data versus similar estimates obtained from the R&M design and development program. The study identifies the major limitations in the field data for use in field R&M

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assessment. Recommendations for improving the quality and usability of the field data are also made.

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PREFACE

This technical report was prepared as an in-house effort within the R&M Engineering Techniques Section (RBRT) of the Reliability Branch (RBR) and the Reliability and Compatibility Division (RB), respectively, at RADC.

The study was done in two separate calendar time periods. Early efforts were concerned with investigations into the details of the field maintenance data collection systems, the procedures to be used for the data compilation and preliminary analyses of the data. The results of this early work, which are covered mainly in Sections 1-3 of the report, were presented at that time in various briefings at Hq AFSC and at RADC. These early efforts also provided some of the groundwork for additional contractual studies into the field operational influences on the reliability and maintainability of electronic equipment.

The second phase of the work, which is covered in Sections 4-7 of the report, was done more recently after more detailed analyses of the field data were done. Hopefully, the conclusions and recommendations made in the report will foster improvements in the field data, as well as provide guidance to other DoD agencies and/or contractors who may be faced with using field maintenance data for R&M assessments.

Acknowledgement is given to Mr. George Lyne (RBRT) for his assistance in preparing some of the computer plots contained in the report, Mr. Irvin Krulac of the Reliability Analysis Center (RBRAC) for his

assistance in providing details regarding the field data collection forms, and to Mrs. Johanna Leonard and Mrs. Patricia Parkhurst for their typing and chart preparation assistance.

The helpful suggestions provided by Messrs. Anthony Coppola and Lester J. Gubbins of RBRT are also appreciated.

SUMMARY

Reliability and Maintainability (R&M) field performance data obtained from Air Force field mainentance data reporting systems, represent a potentially very valuable source of information for R&M technique development and improvement. The extremely large samples of "real world" R&M data, which result from field operation, are not available from any other source. Field R&M data analyses, grounded upon good quality field data, can provide the bases for evaluating the effectiveness of the R&M assurance efforts that went into the design, testing and screening of the equipment and its components. Good quality field data not only can be used to improve R&M assurance techniques for new systems programs, but can also be used for improving the R&M and lowering the support costs of currently fielded equipment.

Air Force maintenance and equipment status reporting systems were designed primarily for logistics, maintenance, and inventory management, rather than specifically for field R&M analysis purposes. Attempts at using the field data for R&M analyses have been the source of much concern regarding the quality and usability of the data. Recently, there have been improvements made in the data systems as a result of the efforts of special groups which were established to address the field R&M data improvement issue. There remains, however, a need for good quality field R&M data which can be used for fully achieving field R&M assessment objectives.

This study was undertaken to determine the extent to which Air Force maintenance data systems can be used for achieving specifically defined R&M

analysis objectives. Various comparisons of field derived R&M estimates at the part, board and equipment levels, versus corresponding estimates derived during the equipment R&M development program, were made in the study for a sample ground electronic system. In attempting to perform such analyses, the limitations of the current data systems were pointed out and recommendations for improvement were developed.

The study has shown that much of the data needed for field R&M assessments are already contained in the current data systems or can be obtained in combination with associated maintenance documentation. In fact, the levels of analysis detail attained through the study go much further than was formerly thought possible. The data systems fall short in important areas, however, which severly limit their use for fully achieving R&M analysis objectives. It was found that, although field data collection procedural improvements are needed, the most important improvements required fall outside the scope of field maintenance data system procedures. Some of the key data required to perform field reliability assessments (e.g., knowledge of root causes of failure) cannot be provided by field maintenance personnel. These and other inputs to field R&M assessment efforts must be developed by the group or agency responsible for the R&M data collection and analyses.

The findings of the study and the data compilation procedures discussed in the body of the report can be used for guidance in performing similar field R&M assessments for other ground electronic equipments. Recommendations for improving the quality and usability of R&M data, collected from the

field, are made in the report. It is believed that implementation of the recommendations by both the R&M groups responsible for the data collection and analysis, as well as by cognizant Air Force agencies, will provide for further developments and use of this very valuable source of R&M data.

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1.0 INTRODUCTION

Analysis of the Reliability and Maintainability (R&M) characteristics of military electronic equipment in the field use environment can be a very useful tool for R&M techniques development and applied research. When good quality field data are available, then the field derived R&M estimates represent the final proof of the effectiveness of all of the R&M assurance efforts that went into the design, testing, and screening of the equipment and its components. There are many reasons why detailed R&M analyses of field performance data should be done. Given reasonably complete and accurate field data, some of the objectives and benefits which can be derived in performing such analyses are:

(a) Correlation of R&M design prediction and laboratory demonstration/test data with field results can be performed to assess and identify the need for improvements in these R&M assurance and control techniques.

(b) R&M problem areas can be isolated and corrective actions can be taken to improve equipment performance and reduce support costs in the field.

(c) Realistic R&M requirements and engineering data can be developed for application to new system programs.

(d) Field experience histories for a variety of equipments can be retained in a data bank for use in the development of improved R&M techniques which more accurately reflect the field use environment.

(e) Field failure and repair-time statistical distributions can be analyzed for compatibility with the distribution assumptions which were

used during the design and development stages.

(f) Part failure rate estimates can be derived from the field data based upon large data samples, otherwise not obtainable, which can be used to verify and/or modify MIL-Handbook failure rate values used in the reliability predictions.

(g) Evaluation of "lessons-learned", and the need for improvements in various elements of the R&M program which was conducted during design, development and production (i.e., part/assembly screening, growth tests, environmental tests, etc.) can be made.

(h) Field R&M performance can be monitored to determine if degradation has occurred due to faulty maintenance practices, changes in the maintenance concept, or to inadequate replacement spares procurement programs.

R&M analyses of field data, which have as their objectives one or more of those listed above, require good quality field data. Unfortunately, the Air Force maintenance data systems which are currently in use for reporting and processing field malfunction data have not been designed with R&M analyses as a primary objective. As a result, needed data elements are not readily available and the output products from the data systems are not prepared in a manner which facilitates R&M analyses. Traceability of equipment failures to causes at lower assembly levels is not always possible. Part and assembly identifications between corresponding hardware elements of the design prediction and the field failure data also present a perplexing problem. In addition, errors and omissions in the field reported data contribute to the difficulties in performing meaningful R&M analyses.

Nonetheless, the limitations in the Air Force data systems may be compensated for in some respects. Useful analyses can perhaps be performed by: taking advantage of the large quantities of data which are available; using supplemental information (parts identification lists, technical manuals, etc.) to aid in resolving hardware identification ambiguities; combining field data which are collected jointly under separate data systems and exercising necessary caution either in interpreting or by censoring any obviously questionable or incomplete data. The problem then is to determine the extent to which Air Force maintenance data can be used for field R&M assessment purposes and to develop recommendations for improving the data systems and procedures for use in field R&M evaluations.

1.1 Objective and Approach

The objective of this study was to use the information which is available from Air Force maintenance data systems, and other related sources, to the maximum extent possible, for the analysis of the R&M characteristics of a fielded ground electronic equipment. Since the data available for analyses are known to be deficient in some respects, analytical objectives outlined in the previous introductory section were adhered to as general goals rather than as firm objectives.

The approach for the study was to use, as a study vehicle, a diversely deployed, ground-based electronic equipment for which R&M program and field data were readily available. Standard Air Force field maintenance data, collected from various field operating sites, were used in the R&M analyses. Failure rate estimates obtained during the design and development

stages, at the part, subassembly and system levels were compared against similar estimates derived from the field maintenance data. In addition, verification and evaluation of the failure and repair-time statistical distribution assumptions used during the design and development stages, with field experience data, were also made. Thus, in attempting to perform such analyses, the limitations in using current Air Force maintenance data systems for the R&M analysis objectives outlined in the introduction of the report, were pointed out and recommendations for improvements were developed.

1.2 Air Force Maintenance Data System Overview

The Maintenance Data Collection (MDC) System established by the Air Force Manual 66-1, "Maintenance Management", and the "Standard Aerospace Vehicle and Equipment Status Report", established by AF Manual 65-110 are the primary sources of R&M field data in the Air Force. These manuals, and their associated documentation, provide the detailed instructions for completing the reporting forms (AFTO 349 and 350), (AF Forms 182 or 2445) by the Air Force field technicians and for the subsequent processing of the data. The completed data forms are compiled at central data processing facilities which provide editing, sorting, summary report preparation and distribution functions. The computer processed output products from these data systems were the source of the R&M field data on which the analyses in this report were based. The following is a brief description of each of the data systems.

The MDC system was designed primarily as a base level maintenance management system. The objectives of the system are to provide maintenance

managers with information on the maintenance accomplished by assigned personnel, to identify the equipment on which work was accomplished, to identify the reasons why the work was required and the actions required to complete the maintenance job. All maintenance actions involving direct labor expenditure such as scheduled inspections, preventive maintenance, and unscheduled maintenance, both on-line and off-line, are reported in the MDC system. Data on material consumption are also reported to facilitate spares management.

The AFM 65-110 Equipment Status Reporting System (ESR) was designed to provide three separate reporting functions, which are:

(a) Inventory Management: The quantities of specific equipment types which are assigned to a given organization are reported to the managing activity. Inventory records are maintained by equipment serial number and are periodically changed by the reporting of gain, loss or termination transactions.

(b) Equipment Status: Equipment status monitoring is accomplished by the reporting of "Not Operationally Ready" (NOR) conditions for each fielded equipment. For example, when the equipment is down for maintenance, the start and stop times for the downtime are reported and the malfunctioning item responsible for the (NORM) condition is identified. In addition, downtime is also reported for conditions other than maintenance (i.e., supply delays, training, etc.).

(c) Equipment Utilization: The utilization of the equipment in terms of mission type, elapsed flying time, etc., are reported for

avionic type equipment. For ground electronic equipment, as is the case for the equipment selected for use in this study, the reporting is on the basis of exception to normal conditions. For example, since the mission of the equipment requires 24 hour per day operation, the equipment is considered operating unless a form is submitted indicating that the equipment is down for maintenance or for other reasons.

Details of the MDC and AFM 65-110 systems, including copies of the forms used (AFTO 349 and AF Form 182) and the data elements contained on the forms are provided in Appendix A. A comparison of the data elements contained on the forms against a composite list of elements needed for R&M assessment is made in Appendix B.

1.3 Equipment Selected for Use in the Study

The equipment used for the R&M analyses is part of an advanced, ground-based, digital processing system which is used by the Air Force and the Federal Aviation Administration in support of air traffic control and surveillance requirements. The equipment was initially fielded in 1972 and is identified by the Air Force nomenclature AN/FYQ-47. Briefly, the function of the AN/FYQ-47 is to receive raw radar and beacon inputs from associated equipment, reject data caused by weather, ground clutter and noise, and perform statistical detection to determine the presence of aircraft. The digital data, derived from the processing of the raw input information, are inserted into appropriately formatted standard messages which are transmitted over telephone lines to central processing locations.

From a R&M viewpoint, the AN/FYQ-47 is comprised of approximately

17,000 electronic parts, 6,250 of which are monolithic microcircuits, 2,400 transistors and diodes, and over 8,000 capacitors and resistors. Practically all of the electronic components are contained on 808 plug-in circuit boards which form the basic on-line replaceable units in the event of malfunction. The mechanical and electromechanical components of the AN/FYQ-47 represent a very small proportion of the overall part complement and include servo-mechanisms, gear trains, switches, and tracking hardware.

Corrective maintenance on the AN/FYQ-47 is facilitated by the use of built-in-test equipment which provides for fault localization to small groups of replaceable plug-in circuit boards. Removal and replacement of the circuit boards must be performed in a specific sequence until it is determined, via appropriate technical manual test procedures, that the failed condition has been corrected. Removed circuit boards are then checked on an off-line card tester (AN/FYM-27) where fault isolation to piece-parts (capacitors, microcircuits, transistors, etc.) and subsequent repairs of the boards are accomplished. Repaired circuit boards are returned to spares stock. Some of the equipment (e.g., power supplies) contain hard-wired components which must be replaced on-line in the event of failure.

2.0 RELIABILITY AND MAINTAINABILITY PROGRAM DATA

During the design, development and production of the AN/FYQ-47, an R&M program was conducted, in accordance with Mil-Standards 785[1] and 470[2], to provide the necessary controls and assurances that the contractually specified R&M requirements for the equipment could be achieved. As part of the program, R&M design predictions were developed to assess if the equipment design, i.e., quality and stress levels of the parts used, use of built-in-test equipment, modularity, redundancy, etc., result in an equipment capable of meeting the specified R&M requirements. In addition, controlled and monitored R&M demonstration tests were conducted to formally demonstrate that the equipment could meet or better the specified R&M requirements. Other reliability assurance efforts, such as parts screening and equipment burn-in testing, were also conducted as part of the reliability program.

The following sections provide a brief description and the results of each of the R&M program efforts. Since the reliability prediction and demonstration mathematical models are to be referred to in the field data analyses sections of the report, a brief discussion of some of the assumptions underlying these models is also presented.

2.1 Reliability Design Prediction

The contractually specified reliability requirement for the AN/FYQ-47 was a MTBF of 545 hours. A reliability prediction was performed for the

(1) MIL-STD-785, "Reliability Program for Systems & Equipment Development and Production", 28 Mar 69.
(2) MIL-STD-470, "Maintainability Program Requirements for Systems and Equipments", 21 Mar 66.

equipment using failure rates contained in the RADC Reliability Notebook(3). The current MIL-HDBK-217B(4) has since replaced the former Notebook.

Figure 1 below, shows the reliability model for the AN/FYQ-47 and the respective predicted failure rates for various functional groups which make up the equipment. Both a series and parallel structure describe the reliability operation of the equipment.

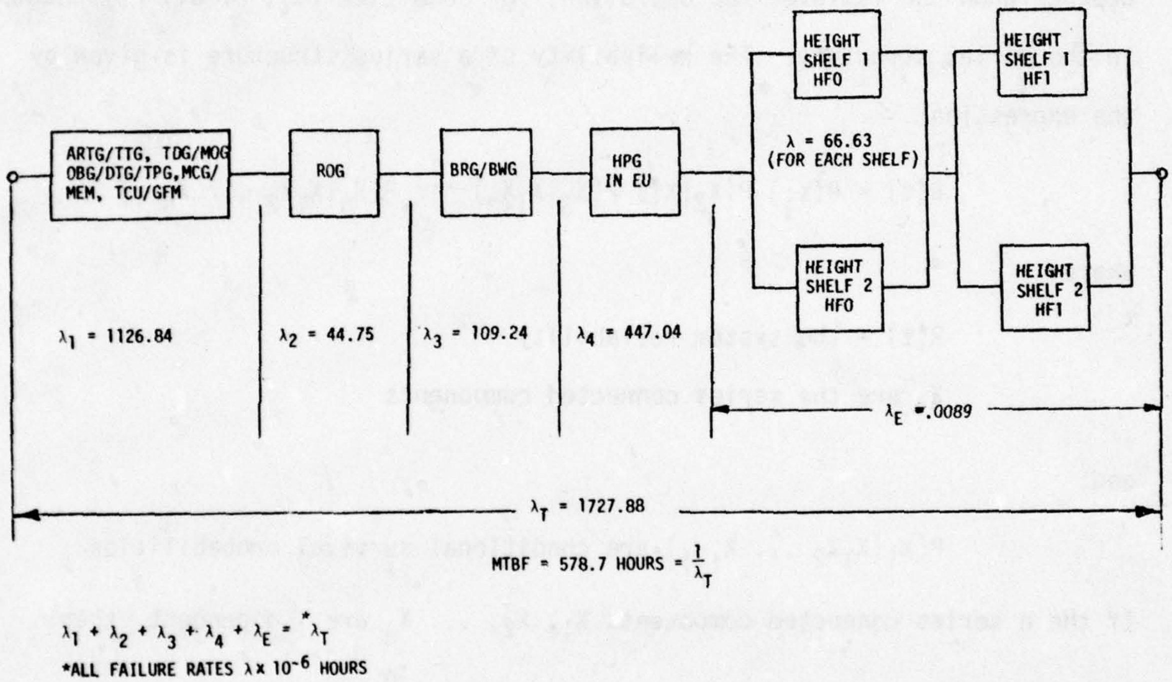

FIGURE 1. AN/FYQ-47 RELIABILITY PREDICTION MODEL

As can be noted, the total predicted failure rate for the AN/FYQ-47 is dominated by the series elements. The reliability prediction model

(3) "RADC Reliability Notebook", Vol II, RADC-TR-67-108, Nov 67.
(4) MIL-HDBK-217B, "Reliability Prediction of Electronic Equipment", 20 Sep 74.(821 640)

includes calculations for redundancy with repair and, as shown by the equivalent failure rate λ_E of $.0089 \times 10^{-6}$, the system failure rate contribution of the parallel structure is negligible. The discussion below, therefore, regarding the assumptions underlying the reliability prediction model, is given in a series context.

In a series configuration, the successful operation of the system depends upon the failure-free operation, for some time (t), of all components in the series structure. The reliability of a series structure is given by the expression:

$$R(t) = P(X_i)\, P(X_2|X_1)\, P(X_3|X_1X_2) \cdots P(X_n|X_1X_2 \ldots X_{n-1})$$

where:

$R(t)$ = the system reliability

X_i are the series connected components

and:

$P(X_i|X_1X_2 \ldots X_{i-1})$ are conditional survival probabilities.

If the n series connected components $X_1, X_2, \ldots X_n$ are independent, then:

$$R(t) = P(X_1)\, P(X_2)\, P(X_3) \cdots P(X_n) = \prod_{i=1}^{n} P(X_i)$$

If also, in addition, each component X_i has a constant failure rate λ_i, then the exponential failure density function is appropriate so that:

$$R(t) = \prod_{i=1}^{n} e^{-\lambda_i t} = \exp\left(- \sum_{i=1}^{n} \lambda_i t\right)$$

In order for the former exponential model to hold then, the

following must be generally true:

(a) The system reliability configuration must be in series.

(b) The individual components must have a constant failure rate.

(c) The individual components must be, both in a functional and statistical sense, independent.

It should be noted, however, that although the individual component failures may be representative of non-constant failure rate processes, it has been shown that if a large number of such processes are pooled, then the distribution of the times between failures for the system approaches the exponential.

Under the assumptions discussed in the previous paragraph, and using the reliability model depicted in Figure 1, the predicted MTBF for the AN/FYQ-47 was determined to be 578.7 hours. The predicted MTBF value can be interpreted as the inherent MTBF of the equipment, given that the part quality levels and the design were not compromised by poor workmanship, process or quality controls during the manufacture of the equipment and its components. The predicted MTBF of 578.7 hours thus indicated that the equipment design, potentially at least, was capable of meeting the contractually specified 545 hour MTBF requirement.

2.2 Reliability Demonstration

The AN/FYQ-47 was subjected to two reliability demonstration tests.

During the development program, one equipment was operated continuously for 1,271 hours without any system outages. Failures occurred in the redundant height shelves, but at no time were both shelves inoperative resulting in a total system outage. A second controlled test was also performed on one production system. The test was a sequential test similar to MIL-STD-781[5], Test Plan V. This test plan is based upon the assumption that the failure rates are constant and that the exponential failure model is applicable. During the test, the equipment was operated continuously and performance was checked three times a day. The test was terminated with an accept decision with one relevant failure at 1,650 hours of operation. Given that the exponential failure model is applicable, the lower 90% confidence limit on the MTBF is given by:

$$\hat{\theta}_L = \frac{2T}{\chi^2(\alpha, 2r)}$$

where

r = the number of failures

T = operating time

α = 10%

χ^2 = Chi-Square variable with $2r$ degrees of freedom

or

$$\hat{\theta}_L = \frac{2(1650)}{\chi^2(.1,2)} = \frac{3300}{4.61} = 715.8 \text{ hours}$$

Thus, the demonstration results indicate that the sample production

(5) MIL-STD-781, "Reliability Tests, Exponential Distribution", 15 Nov 67.

equipment surpasses the 545 hour MTBF requirement. Obviously, assessments as to whether the remaining production equipments have met the requirement can only be made from analyses of the field data.

2.3 Parts Control, Screening, Equipment Burn-In

All monolithic microcircuits contained in the equipment were subjected to quality assurance screening tests per RADC Specification 2867A[6], the forerunner to the present MIL-STD-883[7]. Controls by production lot and device type were implemented to ensure identification of bad lots and corrective actions where required. Part screening tests included precap visual inspection, thermal shock, centrifuge, hermeticity and burn-in of 240 hours at 125°C. Limit tests on samples of various production lots were also performed to establish the limits of the stress which the microcircuits could withstand and to identify the failure modes involved.

In addition to the 100% screening of all microcircuits, a controlled 100 hour system burn-in test at the factory was performed prior to shipping each system to the field. The purpose of the burn-in test was to weed-out, identify, and correct in subsequent production units, early failure patterns (workmanship, substandard parts, etc.) in the equipment.

2.4 M Design Prediction

The contractually specified maintainability requirement for the AN/FYQ-47 was a mean-time-to-repair of .5 hours and a maximum time-to-repair (98th percentile) of 2 hours. A maintainability prediction for the equipment

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(6) RADC Specification 2867A, "Quality and Reliability Assurance Procedures for Monolithic Microcircuits", 30 Jan 67.
(7) MIL-STD-883, "Test Methods & Procedures for Microelectronics", 15 Nov 74.

was performed using Procedure II of MIL-HDBK-472[8]. The maintenance design concept on which the prediction was based included:

(a) Automatic fault localization via built-in-test with the occurrence of a fault made known by audio or video alarm.

(b) Fault isolation to a specific board by use of fault diagnosis and specific board replacement schemes contained in the maintenance procedures.

(c) Replacement of the defective board by an operational spare and subsequent off-line repair of the board with the aid of a board tester. Off-line repair time was, of course, not included in the maintainability prediction.

Based upon the former maintenance design concept, and use of Procedure II, the predicted mean-time-to-repair (MTTR) for the AN/FYQ-47 was determined to be 24.8 minutes. Again, this value can be interpreted as the inherent "designed-in" MTTR of the equipment. It should be noted, however, that Procedure II relies rather heavily on subjective estimates of repair times by the maintainability analyst.

2.5 M Demonstration

A maintainability demonstration test was conducted at the contractor's plant in accordance with MIL-STD-471[9], Test Method 1. Fifty (50)

(8) MIL-HDBK-472, "Maintainability Prediction", 24 May 66.
(9) MIL-STD-471, "Maintainability Demonstration", 27 Mar 70.

maintenance tasks were randomly selected and faults were inserted into the equipment to simulate equipment failures. Air Force and FAA technician personnel were used in the demonstration to perform the repair actions for the simulated failures. Based upon actual timings of the 50 maintenance tasks used in the demonstration, a MTTR of 17.5 minutes was demonstrated, with 98% of the maintenance tasks being accomplished in less than two hours. The demonstration results thus surpassed the specified maintainability requirements. However, it is well known that demonstrations, in general, are conducted under ideal conditions. Maintenance in the field includes many operational influences which are not and cannot normally be accounted for in the demonstration. Analyses of field repair time data can, however, provide a means of evaluating the effectiveness of the procedures and the accuracy of the estimates derived from the maintainability prediction and demonstration techniques.

3.0 FIELD DATA COMPILATION AND PRELIMINARY ANALYSES

Prior to obtaining the data to be used for the analyses, a review of the standard Air Force maintenance data collection and processing procedures was initially made. As a result of the review, it was found that the information required to perform the analysis was not provided completely in any single standard computer output data product. It was therefore, necessary to obtain the data from several sources, have it machine processed in a special chronological manner so that the information could be combined and compiled for the analyses.

Figure 2 illustrates the various elements of the data reduction and study plan. The raw data sources in the field are shown as the Maintenance Data Collection Record (MDC) (AFTO Form 349) and the Equipment Status Report (ESR) (AF Form 182). Details regarding the data elements contained on these forms are provided in Appendix A. As was discussed previously in Section 1, the MDC system contains information pertaining basically to resource expenditures of manpower and materials for corrective and preventive maintenance. The ESR data provides information on the equipment operating status and utilization in terms of downtime for maintenance, training, supply delays, etc. By combining these data sources, it was possible to obtain many of the data elements needed for the R&M analyses, although with some missing detail.

Figure 2 also illustrated that it was necessary to use the maintenance and work unit code manuals, the servicing and inspection instructions, the illustrated parts breakdown and parts cross-identification lists for the equipment selected for use in the study.

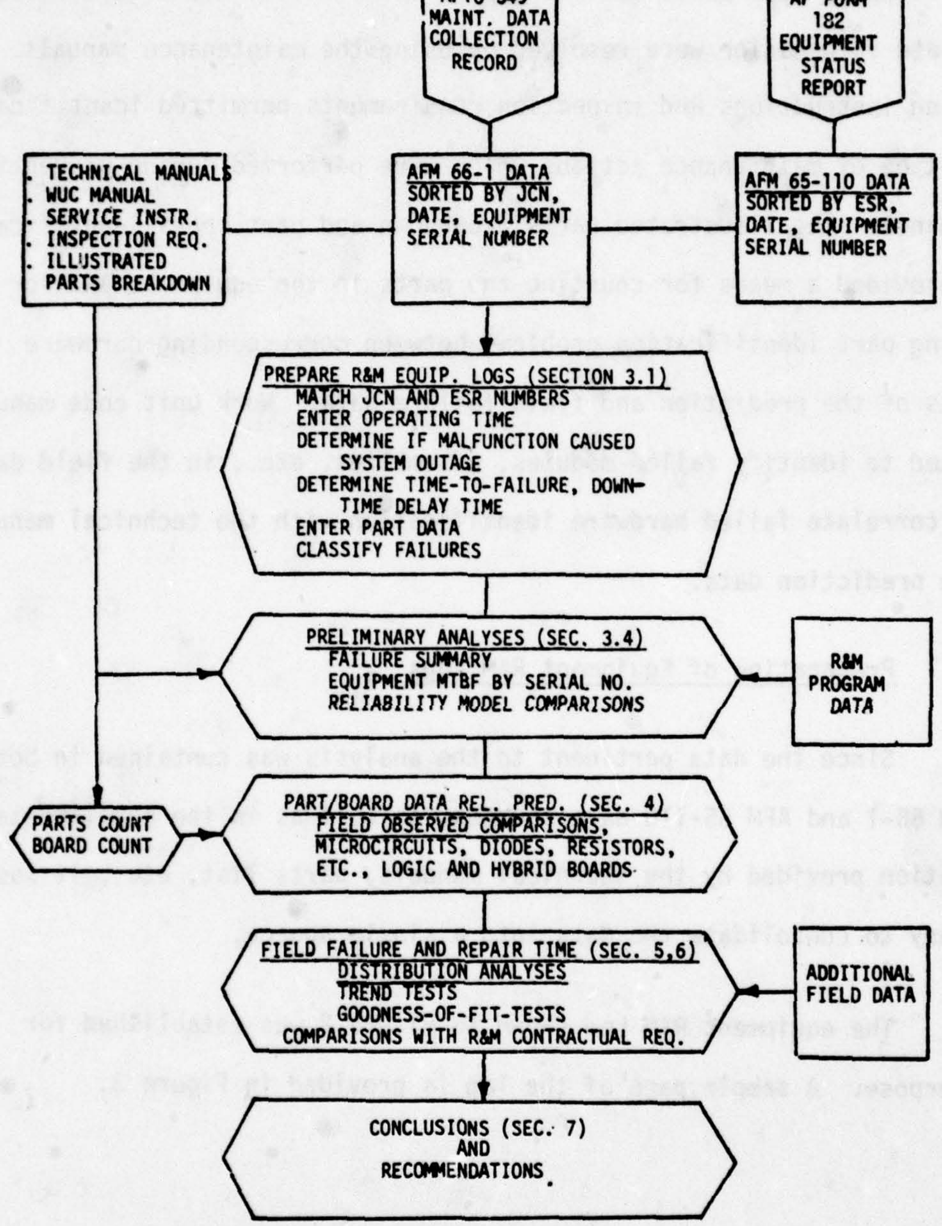

FIGURE 2. DATA COMPILATION AND STUDY PLAN

The former documents served several purposes. Some of the discrepancies in the field data, such as failed board/part identification ambiguities or incomplete information were resolved by using the maintenance manuals. The servicing instructions and inspection requirements permitted identification of the type of maintenance actions which were performed during preventive maintenance. The illustrated parts breakdown and part cross-identification lists provided a means for counting the parts in the equipment and for resolving part identification problems between corresponding hardware elements of the prediction and field failure data. Work unit code manuals were used to identify failed modules, assemblies, etc., in the field data and to correlate failed hardware identification with the technical manuals and the prediction data.

3.1 Preparation of Equipment R&M Logs

Since the data pertinent to the analysis was contained in both the AFM 66-1 and AFM 65-110 data sources, as well as in the supplementary information provided by the technical manuals, parts list, etc., it was necessary to consolidate the data into a single source.

The equipment R&M Log shown in Fiqure 2 was established for this purpose. A sample page of the log is provided in Figure 3.

THIS PAGE FROM ______ TO ______

AVAILABLE HOURS ______
DOWNTIME PM ______ CM ______
DELAY TIME ______
OPERATING HOURS ______

SERIAL NUMBER ______
LOCATION ______

JCN	WUC	DATE	AT	WD	HM	RG/R/N	AG/A/N	TTF	DOWN TIME	DELAY TIME	FSC	REPL PART NO.	HM	REF DES			COMMENTS

FIGURE 3. SAMPLE EQUIPMENT R&M LOG

Using a chronological sort of the data, and by matching either calendar dates or the Job Control Number (JCN) in the AFM 66-1 data with the Equipment Status Report Number (ESR) in AFM 65-110 data, it was possible to identify for many of the malfunctions and for each equipment:

(a) The item or items which failed or were replaced (Work Unit Code (WUC)).

(b) Whether the malfunction caused partial or total system outage (RG/RN) or (AG/AN).

(c) The parts replaced as the result of the malfunction (Federal Stock Code, Part Number, Reference Designator).

(d) The operating time between malfunctions.

(e) The type of maintenance action (preventive or corrective).

(f) Maintenance downtime, supply and administrative delay times.

(g) Equipment operating time.

(h) Coded information pertaining to when the malfunction was discovered (WD), how the item malfunctioned (HM), and the action taken for the repair (AT).

Operating time for each equipment was obtained by subtracting the maintenance and delay downtimes from the total available calendar time. Since the mission of the equipment requires 24 hour per day operation, the equipment was considered operating unless the data indicated it was down for maintenance, logistic or administrative delay. It should be noted, however, that it was not generally possible to positively identify the primary hardware cause of the system malfunction. Omissions in the data and maintenance actions involving multiple board or part replacements generally prevented such identification. In addition, it should be recognized that the Air Force field technician is primarily motivated to "fix" the equipment and not to isolate failure causes. As a result, the field data tend to reflect replacement actions which were performed to facilitate the repair rather than specifics regarding the cause of failure.

3.2 Study Plan

Figure 2 on page 17 also illustrates the sequence of the various data compilation and analysis tasks of the study plan.

The Equipment R&M Logs were initially compiled using one year of field operational data on 31 equipments which were located at different Air Force sites within the United States. As shown in Figure 2, the data were used in a preliminary analyses contained in Section 3.4 of the report, to determine if the data were of sufficiently good quality to attempt performing further analyses. The preliminary analysis indicated that the data were reasonably usable for more detailed part level and failure/repair-time distribution analyses. Comparisons of predicted versus observed failure rates are made in Section 4 of the report for the parts and circuit boards contained in the equipment. An additional nine months of field operation data were compiled for 25 of the 31 equipments, which were combined with the data collected earlier for the preliminary analyses. Using the additional data, failure distribution analyses, including trend tests and goodness-of-fit tests, are performed in Section 5 and comparisons with prediction and demonstration statistical distribution assumptions are made. The field maintainability characteristics of the equipment are evaluated in Section 6 of the report. Conclusions and recommendations are presented in Section 7.

3.3 Failure/Malfunction Classifications

In the process of compiling the Equipment R&M Logs, it was found that both the AFM 66-1 and AFM 65-110 data records were incomplete. For example, it was possible to match the Job Control Number (66-1 data) with the Equipment Status Report Numbers (65-110 data) in only 54% of the total reported malfunctions. In addition, some of the malfunctions involved multiple board or part replacements without any indication of which board or part was the primary cause of failure. In other instances, a single

board replacement was indicated in the data without any follow-on part failures or replacements. It was also found that some of the failures were in redundant channels and did not cause system outages or were in associated test equipment. Other malfunctions listed in the data were discovered during the performance of daily or phased inspections for which the equipment is taken down on a scheduled basis.

Lastly, some apparent malfunctions were listed with extensive troubleshooting times, but with no subsequent repair or replacement actions. It was thus necessary to establish a method for classifying the malfunctions, as the data were being compiled, so that a count of failures could be reasonably made. The following general categories were established for this purpose:

TABLE 1. FIELD MALFUNCTION CLASSIFICATIONS

CATEGORY	DESCRIPTION
0	Multiple board replacement/equipment level failure.
1	Single board replacement with part level data.
2	Single board replacement without part level data.
3	Adjustments (action taken codes "L").
4	Replacement of "minor" parts (action taken code "G").
5	Equipment malfunction listed only in AFRM 65-110, parts level data correlated with AFM 66-1 data.
6	Troubleshooting (action taken code "Y"), with no replacement actions listed.
7	Cleaning (action taken code "V").
and:	
A	Caused downtime (unscheduled maintenance).
B	Downtime (scheduled maintenance).
C	Failure in redundant channels and/or did not cause system downtime.
D	Failure of off-line test equipment.
E	Failure listed in AFM 66-1, but not in AFM 65-110 data.

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and:	
A	Caused downtime (unscheduled maintenance).
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and:	
A	Caused downtime (unscheduled maintenance).
B	Downtime (scheduled maintenance).
C	Failure in redundant channels and/or did not cause system downtime.
D	Failure of off-line test equipment.
E	Failure listed in AFM 66-1, but not in AFM 65-110 data.

For example, classification A1 indicates an unscheduled maintenance incident which caused a total system outage, where a single board was replaced with corresponding part level replacement data reported. Classification of the malfunctions in this manner thus permitted greater flexibility in the data analyses and also enabled an evaluation of the analysis results in terms of the data completeness.

3.4 Preliminary Analysis of the Field Data

The preliminary analysis in this section includes a summary of the classified failures for all 31 equipments, calculations of the field MTBF for each equipment and comparisons of the failure rates of the prediction model with those derived from the field data. The purpose of the preliminary analysis was to determine if the data were of adequately good quality to attempt more detailed evaluations. All of the calculations of failure rates (MTBF) in this section were based on the assumption that the failure rates are constant.

3.4.1 Malfunction Classification Summary and Failure Counts

Table 2 provides a summary of the classified failure data for the 31 equipments. During the one year data sample period the 31 equipments were operated for a total of 169,687 hours. Not all of the equipments were operated for the full year since some had been placed into field operation at various times within the year. The failure categories described in the previous Section 3.3 were used as a basis for either excluding or counting the failures used in the MTBF calculations for the equipment.

TABLE 2. FAILURE CLASSIFICATION SUMMARY

MALFUNCTION CATEGORY[a]

MALFUNCTION CATEGORY[a]	0	1	2	4	5	TOTALS	3	6	7
A	11	39	42	20	76	188	71	5	5
E	5	35	13	4	-	57	8	13	1
TOTALS	16	74	55	24	76	245	79	18	6
B	1	11	7	1	-	20	4	-	-
C	-	25	11	21	13	70	9	3	13
D	1	13	8	4	9	35	9	2	3
TOTALS	2	49	26	26	22	125	22	5	16

[a] See Table 1, Section 3.3

Cleaning actions (Categories A7, E7), failures in off-line test equipment (Category D) and troubleshooting (Categories A6, E6) were excluded from the failure count. Malfunctions which were in redundant channels (Category C) and did not cause system outages were not counted against the system MTBF. None of the failures in the redundant height shelves were found to cause the system to go down. The primary failure count of unscheduled corrective maintenance incidents were the classifications A0-A2, A4, A5 and E0-E4, which resulted in a total of 245 failures. Unscheduled "adjustments" (total 79, Category 3) and the maintenance actions which were performed as the result of preventive maintenance (total 20, Category B) were grouped and added separately to the failure count to assess their relative effects on the equipment MTBF. The reasons for considering these malfunction categories in the count of failures are discussed.

Most of the maintenance actions which were reported as

"adjustments" involved unscheduled downtimes of very short duration (1-3 minutes). Others, however, had longer associated downtimes (30-60 minutes) and there is some question as to whether some should perhaps be counted as failures. A case can be made for counting some of the adjustments as failures, given that the data provide adequate detail regarding the nature and reason for the adjustment. However, it was not possible to distinguish from the source data, which "adjustments" were legitimately countable; therefore, for general comparison purposes all were grouped and separately combined with the primary failure count.

Maintenance actions which were performed during preventive (scheduled) maintenance periods were found to contain part, as well as board replacements. It was found, through a visit to one of the field sites (Saratoga Springs NY) that, on occasion, corrective maintenance is postponed to periods of scheduled downtime (normally once per day). Therefore, rather than exclude the preventive maintenance actions from the failure count, they were also grouped and separately combined into the total failure count.

The average MTBF for all systems combined using the classification (A0-A2, A4, A5) and (E0-E4) was calculated as $\frac{169,687}{245}$ = 693 hours which compares favorably with the predicted value of 578 hours. When the Category "B" (preventive maintenance) failures are included, the MTBF is $\frac{169,687}{260}$ = 640 hours and if the adjustments are counted the MTBF is $\frac{169,687}{384}$ = 493 hours.

It should be noted that the standard Air Force computer

printouts which provide MTBF estimates of the equipment would have included all Category C (60 reported failures in redundant height shelves) and Category D (35 reported failures in off-line test equipment) as well as the 79 "adjustments" (Category 3) in the MTBF calculation, thus yielding a MTBF of 396 hours.

The need for consistent field failure definition becomes evident from the former discussions. Data from the field should be sufficiently detailed so that bonafide equipment failures can be distinguished from non-failures. The reliability model should be available for the analysis so that proper accounting of failures in redundant channels can be made. In addition, a review of the equipment configuration should be made to ensure that the same equipment components, assemblies, etc., considered in the design prediction are also included in the field reliability evaluation. As was found with the AN/FYQ-47, the off-line test equipment was included as part of the AN/FYQ-47 configuration in the work unit code manuals. The standardized computer procedures, therefore, count the off-line test equipment failures (Category D) against the AN/FYQ-47.

3.4.2 Equipment MTBF by Serial Number

Table 3 provides a summary of the operating time, number of failures (unscheduled, scheduled and adjustment maintenance actions counted separately) and respective MTBFs for each of the 31 equipments located at different field sites. Generally, there is a rather large variability in the MTBFs among the various sites. Several explanations for the variability can be posed. First, omissions in the reporting of

malfunctions could have occurred at some of the sites. For example, the omission of one or two failures at those sites which had a low number of reported failures (i.e., ≤ 4) could result in a significant change in the MTBF for the equipment located at a given site, yet not affect the overall MTBF average significantly. Secondly, for many of the reported maintenance actions, complete traceability and verification of the malfunction was not possible.

TABLE 3. EQUIPMENT MTBF BY SERIAL NUMBER

EQUIPMENT S/N	OPERATING TIME (T)	(a) UNSCHEDULED MAINTENANCE (A0-A2,A4,A5,E0-E4)	(b) SCHEDULED MAINTENANCE (B0-B4)	(c) UNSCHEDULED ADJUSTMENTS (A3)	MTBF		
					$\frac{T}{(a)}$	$\frac{T}{(a+b)}$	$\frac{T}{(a+b+c)}$
81	5068.6	3	2	1	1689.5	1013.7	844.8
64	7486.2	15	-	2	499.1	--	440.4
85	7587.9	10	-	5	757.9	--	505.9
83	4978.4	5	3	2	955.7	622.3	497.8
147	6000.0	7	-	4	857.1	--	545.5
71	5187.5	5	-	1	1037.5	--	864.6
160	7808.5	3	-	3	2602.8	--	1301.4
137	2296.4	3	-	0	765.5	--	--
75	4735.2	7	-	1	676.5	--	591.8
59	7670.9	13	1	3	590.1	547.9	451.2
49	4320.2	3	6	0	1440.1	480.0	--
63	3599.1	3	-	5	1199.7	--	449.9
79	7865.6	6	-	14	1310.9	--	393.3
89	1941.5	1	-	3	1941.5	--	485.4
133	7273.6	21	1	4	346.4	330.6	279.8
57	6891.8	17	1	6	405.4	382.9	287.2
61	6435.2	6	1	3	1072.5	919.3	643.5
28	4629.5	7	-	1	661.4	--	578.7
125	5327.0	14	-	5	380.5	--	280.4
26	7486.2	11	2	1	680.6	575.9	534.7
123	6271.7	3	-	2	2090.6	--	1254.3
67	6934.5	9	1	1	770.5	693.5	630.4
30	7114.8	16	-	3	474.3	--	374.5
24	7626.1	9	-	0	847.3	--	--
73	4372.2	7	-	2	624.6	--	485.8
69	5409.2	10	-	2	540.9	--	450.8
77	5617.6	8	1	1	702.2	624.2	561.8
141	2844.8	4	-	1	711.2	--	570.0
95	1976.3	10	1	1	197.6	179.7	164.7
93	1987.3	7	-	1	283.9	--	248.4
149	4952.5	3	-	1	1650.8	--	1238.1
TOTALS	169,687.3	245	20	79	692.6	640.3	493.0

Thus, so-called failures could have been malfunctions for which subsequent off-line maintenance might have indicated "no trouble found". Third, initially high failure rates could be present in some of the fielded equipment because of an inadequate weeding-out of early failures (e.g., poor workmanship, substandard parts or materials) during the manufacturing process. The analysis in Section 5 of the report is directed toward examining the failure distribution characteristics of the AN/FYQ-47 in the field.

3.4.3 <u>Reliability Prediction Model and Field Failure Rate Comparisons</u>.

Figure 4 below, provides a comparison of the predicted and observed failure rates using the AN/FYQ-47 reliability model as the basis for comparison.

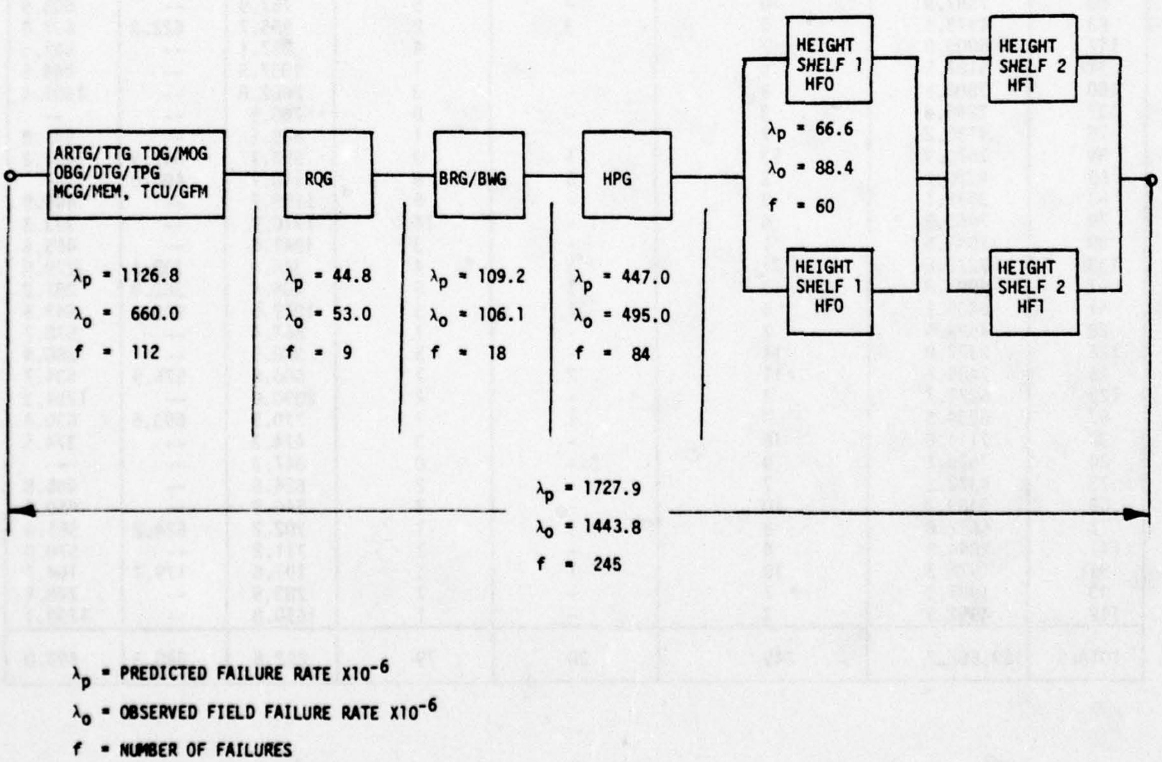

FIGURE 4. RELIABILITY PREDICTION MODEL AND FIELD FAILURE RATE COMPARISONS

As can be noted, the comparisons are remarkably good, in spite of the limitations presented by the data. Included in the preparation of Figure 4 were all the unscheduled maintenance incidents which caused system downtime (Categories AO-A5, AO-A2, A4, A5, EO-E4) of Table 1. For the redundant height shelves the failure rate comparisons were made on a simplex basis. None of the height shelf failures, as indicated by the AFM 65-110 data, resulted in system outage. Of the 245 unscheduled maintenance incidents, it was not possible to isolate 22 to any of the subsystem groups within the reliability model.

The results of the former comparisons were encouraging in that they indicate that the malfunction reporting from the field, at least to the subsystem level, was reasonably complete and accurate. Since obtaining such correlations by chance alone is fairly remote, it was decided to continue with more detailed reliability evaluations at the part and circuit board levels. These analyses and results are discussed in the next Section 4.

3.5 Summary of Findings

(a) The data are generally usable for more detailed analyses at the part level and for failure distribution analyses at the equipment level.

(b) By combining chronologically processed data from the AFM 66-1 and AFM 65-110 data systems, R&M data elements, such as the time-to-failure, and the repair times needed for R&M assessments can be obtained.

(c) Use of supplemental information provided by the equipment technical manuals, illustrated parts breakdown and work unit code manuals

permits obtaining additional needed data elements, as well as resolution of discrepancies in the field data.

(d) Estimates of MTBF provided in standard Air Force data products cannot be relied upon for use in making comparisons against specified or predicted values. This is due primarily to differences in failure definitions. Equipment configuration misidentifications between the design and field also contribute to the error in MTBF estimates provided by the standard data system outputs.

(e) Some bonafide equipment failures may be reported as "adjustments", or may be reported as preventive maintenance, depending on site operating procedures.

(f) A substantial percentage of the data are incomplete at the part level which obviously affects the usability of the data for performing more detailed analyses.

(g) For equipments operating in environments similar to the AN/FYQ-47, it is possible to obtain operating time as well as time-between-failure data at the system level.

(h) It is not possible to obtain more detailed breakdowns of corrective maintenance times such as fault location time, fault correction time, etc. However, provisions for reporting delay times and downtimes for maintenance are included in the data systems procedures.

(i) There are inconsistencies and omissions in the data reported from different sites and in separate data systems. Much improvement can

obviously be accomplished by providing unambiguous instructions on how the data collection forms are to be filled out for reporting failures. Such instructions should be unique, where possible, to the system for which the data are being collected.

(j) Obtaining matching part/assembly identifications between those used for the prediction and those obtained from the field failure data is one of the most time-consuming tasks in attempting to perform field R&M analyses. Use of part vendor assigned generic identifications, equipment contractor assigned part numbers, and government federal stock codes, work unit codes, etc., contribute to such difficulties.

(k) Chronological sorting of the data enables obtaining operating time between failure information as well as facilitating the analyses. Machine processing of the data in the Equipment R&M Log format would be very useful for R&M analysis purposes provided that the data are complete and properly edited prior to processing.

(l) The reliability model for the equipment should be available for the analysis so that proper accounting of failures in redundant channels can be made.

(m) Review of the equipment configuration should be made to ensure that the same major equipment components are included in the field R&M evaluations as were used in the reliability prediction and demonstration.

4.0 PARTS AND CIRCUIT BOARD DATA-PREDICTED/FIELD-OBSERVED COMPARISONS

Appendix C contains tables identifying the parts and circuit boards used in the AN/FYQ-47, their respective quantities, predicted failure rates, expected field failures and observed field replacement rates. It is again noted that some of the maintenance actions involved multiple part/board replacements without the primary cause of failure being identified in the data. Therefore, all replacements were included in Column 4 of the tables of Appendix C and replacement rates rather than failure rates were calculated in Column 5. Calculations in the Appendix C tables were based upon the total accumulated operating time of 169,687 hours for all 31 systems.

4.1 Parts Data

Table 4 below provides a summary of the Appendix C part data showing part counts, expected failures and the observed field replacements for the various electronic part types used in the AN/FYQ-47.

TABLE 4. EXPECTED FAILURES AND FIELD REPLACEMENTS FOR AN/FYQ-47 ELECTRONIC PARTS

PART TYPE	PART COUNT	EXPECTED FAILURES	FIELD REPLACEMENTS
Monolithic Microcircuits	6250	75.7	140
Diodes	647	2.2	3
Transistors	1689[b]	31.4	84
Capacitors	4478	12.9	1
Resistors	3968	51.9	5
	TOTALS	174.1	233

[b] actual quantity 1832
Data was not available on 4 transistor types

Although the overall total field replacements shown in Table 4 are greater (by about 33%) than what the prediction data might have indicated, there are even larger and inconsistent differences within the various part types. Since comparisons of total replacements rather than actual failures were made, one might expect to see the total replacements always larger than the total expected failures. It must also be noted, however, that some of the data were incomplete with regard to the reporting of part level replacements (e.g., Failure Classes A2, E2, A0, E0, A5 in Section 3.3). If each of the former maintenance actions had resulted in part replacement, then obviously the differences in the totals would have been even larger. The data of Table 4 would initially indicate rather poor correlations, as well as cast serious doubts as to the usefulness of the field data for any analyses to the part level. However, when the data for each of the part types are examined further, some interesting findings result.

4.1.1 Microcircuits

The 6250 microcircuits contained in the AN/FYQ-47 were exposed to over one billion (1060.54×10^6) operating hours during the time period in which the data were collected. Figure 5 is a plot of the expected number of failures versus the number of replacements for each of the 21 microcircuit device types used in the equipment. As shown in this figure, the correlation between the expected failures and field observed replacements is remarkably good for the majority of the devices. These results suggest that, at least for the microcircuit devices, fairly consistent and accurate reporting of field replacements were made by the field

technicians at all the sites. The digital nature of the devices may also have a bearing on the good correlations because the failures generally can be more easily and positively identified.

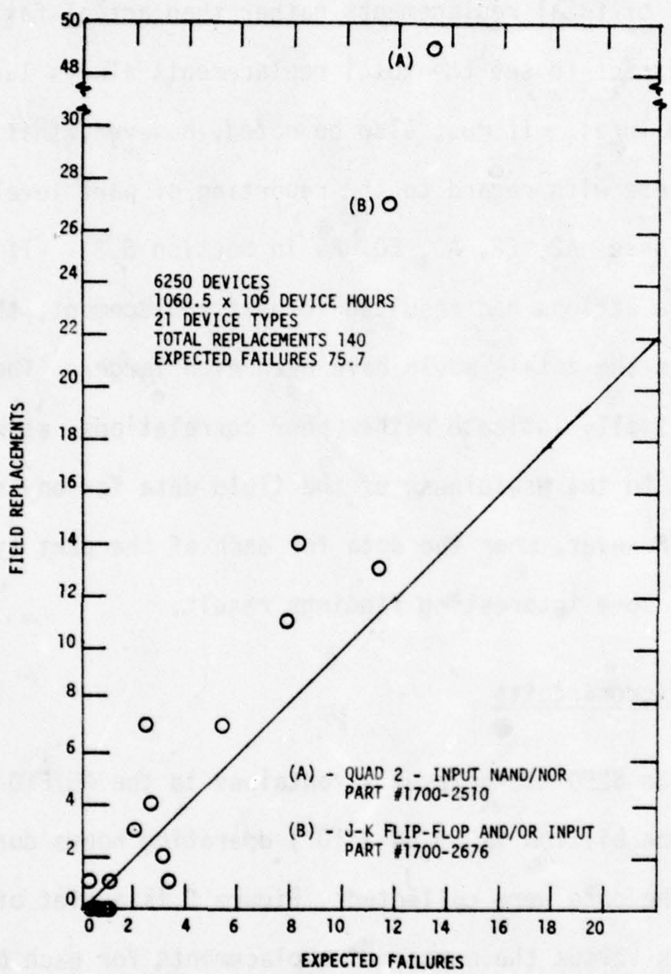

FIGURE 5. EXPECTED FAILURES VS FIELD REPLACEMENTS FOR AN/FYQ-47 MONOLITHIC MICROCIRCUITS

The devices labelled A and B in Figure 5 are the Quad 2-Input Nand/Nor (Part #1700-2510) and the J-K Flip-Flop and/or Input (Part #1700-2676) respectively, which are listed in Appendix C. These devices display

a considerable difference from predicted values and represent 21% of the total microcircuit population in the equipment. Samples of these failed devices would obviously be good candidates for detailed failure analysis, to determine failure causes and corrective actions. Note that the predictions provide a very useful tool, since they serve as a baseline against which field failure frequency can be compared and potential reliability problem areas isolated. It should also be noted, that use of the raw field data, as it is currently being generated, for verifying or modifying handbook (i.e., MIL-HDBK-217B) predicted failure rate values (See Objective "f" in Section 1) would be a highly questionable practice. Additional failure circumstance data, as well as detailed laboratory analyses of failed parts, are required in order to meaningfully achieve such analyses objectives. Data analyses, using the prediction data as a comparison base, does, however, provide a means for selecting field failed devices which offer the greatest pay-off in terms of laboratory failure analysis resources to be expended versus the analyses objectives which are desired.

4.1.2 Diodes and Transistors

During the period over which the data were collected, the diodes had slightly over 100 million device hours, 109.785 x 10^6, and the transistors 286.601 x 10^6 device hours. Overall, the diodes of Table 4 show good correlation (2.2 vs 3) between the expected and observed replacement rates. However, even with the large exposure hours available, individual diode types had limited exposure time due to their relatively small quantities. Therefore, very little can be said about the field performance of the diode

population in the equipment.

The transistors, on the other hand, show a large disparity between the expected and observed replacement rates. Figure 6 rather vividly illustrates the poor correlations.

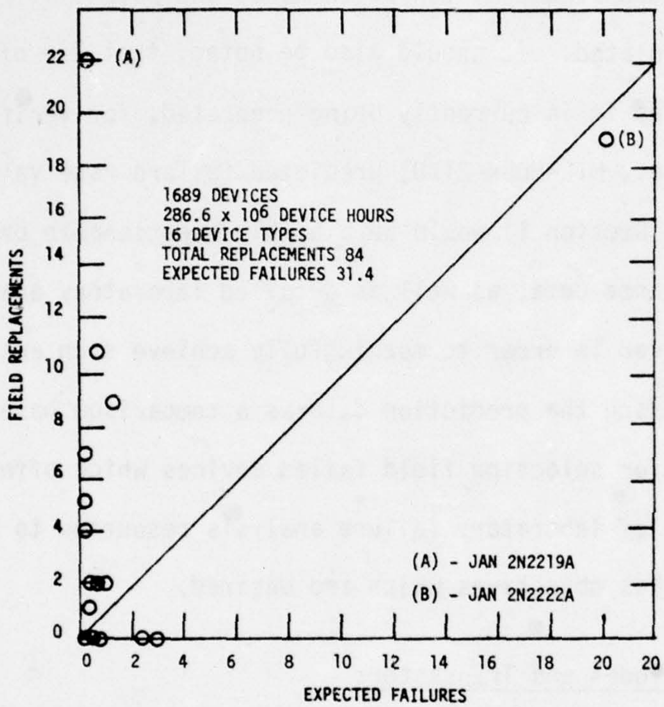

FIGURE 6. EXPECTED FAILURES VS FIELD REPLACEMENTS FOR AN/FYQ-47 TRANSISTORS

Although the data are still somewhat limited, three possible reasons for the poor correlations can be posed:

(a) The values of the predicted failure rates for most of the transistors were overly optimistic.

(b) The transistors are generally of poor quality due to inadequate part screening and controls.

(c) Transistors were replaced in the field by the technicians which were not the primary cause of system failures (i.e., either the transistors upon retest would test "good" or they represented secondary failures).

It is not possible to isolate the cause of the poor correlations to any one of the above reasons, given the quality of the current field data. However, if the data were at least sufficiently accurate to rule out entirely reason (c), then additional efforts (i.e., laboratory analyses of selected failed parts) could be concentrated to determine the cause of the poor correlations and determine corrective actions.

The data, however, are still useful for *isolating potential* reliability problem areas. For example, the devices labelled A&B in Figure 6 have the highest overall replacement rates. When the data for these devices (see Figure 6 and Appendix C) are compared as shown in Table 5 below, it becomes quite obvious that device A, at least until additional failure circumstance data are reviewed and perhaps more detailed failure analysis is done, represents a reliability problem area.

TABLE 5. TRANSISTOR REPLACEMENT COMPARISONS

IDENT.	QTY/EQUIP.	EXPECTED FAILURES	REPLACEMENTS
Device A JAN 2N2219A	6	.1	22
Device B JAN 2N2222A	1185	20.1	19

It should again be emphasized that if there was positive identification and verification of the primary cause of field failures to the part level, without omissions, then part level analyses of this type could be extremely more valuable for achieving field reliability assessment objectives.

4.1.3 Capacitors and Resistors

The capacitors and resistors in the equipments sampled had respectively 759.86×10^6 and 673.32×10^6 device hours during the data collection period. The data of Table 4 show the largest difference between the predicted and field replacement rates for these parts, but in a direction different from the previously listed part types (i.e., expected failures << field replacements). If one were to assume that the field replacement rates are reasonably correct (i.e., few omissions occurred) then some of the failure rates used in the predictions were obviously pessimistic. For example, the RL (MIL-R-22684) fixed film resistors shown in Appendix C, represent 85% of the total resistor population in the equipment and account for the majority of the disparity between predicted and observed replacement rates. The predicted failure rate used for the fixed film resistors was $.072 \times 10^{-6}$, which differs by at least an order of magnitude from the observed replacement rate of $.004 \times 10^{-6}$. On the other hand, there may have been a tendency for the technicians in the field to consider capacitors and resistors "minor" parts and therefore, not record their replacement. The following questions can therefore be posed: Are the failure rate predictions for the capacitors and resistors overly pessimistic? Was there widespread omission at <u>all</u> the sites in reporting capacitor and

resistor replacements? These questions, of course, cannot be reasonably answered using the existing data. However, if data collection procedures were developed to ensure complete and accurate recording of failure data to the part level, then the data could be very useful for evaluations of the type discussed above as well as for other R&M assessment objectives.

4.2 Circuit Board Data

Table 6 below shows the respective quantities, expected failures and field replacements for the logic and hybrid circuit boards contained in the equipment. The logic boards are comprised primarily of microcircuits, while the hybrid boards contain mostly discrete components (semiconductors, capacitors, resistors) as well as some microcircuits. The same operating time base used for the parts in the previous section was used for the expected failure calculations of the circuit boards.

TABLE 6. EXPECTED FAILURES AND FIELD REPLACEMENTS FOR AN/FYQ-47 CIRCUIT BOARDS

TYPE	QUANTITY	EXPECTED FAILURES	FIELD REPLACEMENTS
Logic	617	128.9	160
Hybrid	151[c]	67.2	52
TOTALS	768	196.1	212

[c] actual quantity 191
comparable data was not available on 2 board types

The totals of Table 6 compare rather well, but again a reversal in the number of field replacements, from greater than to less than the

expected failures, is evident in comparing the logic and hybrid boards. Since the hybrid boards contain a majority of discrete passive components, these results as expected, would tend to agree with the parts data (capacitors and resistors) of the previous section 4.1.3.

4.2.1 Logic Boards

Figure 7 is a plot of the expected failures versus field replacements for the 617 logic boards contained in each of the 31 equipments.

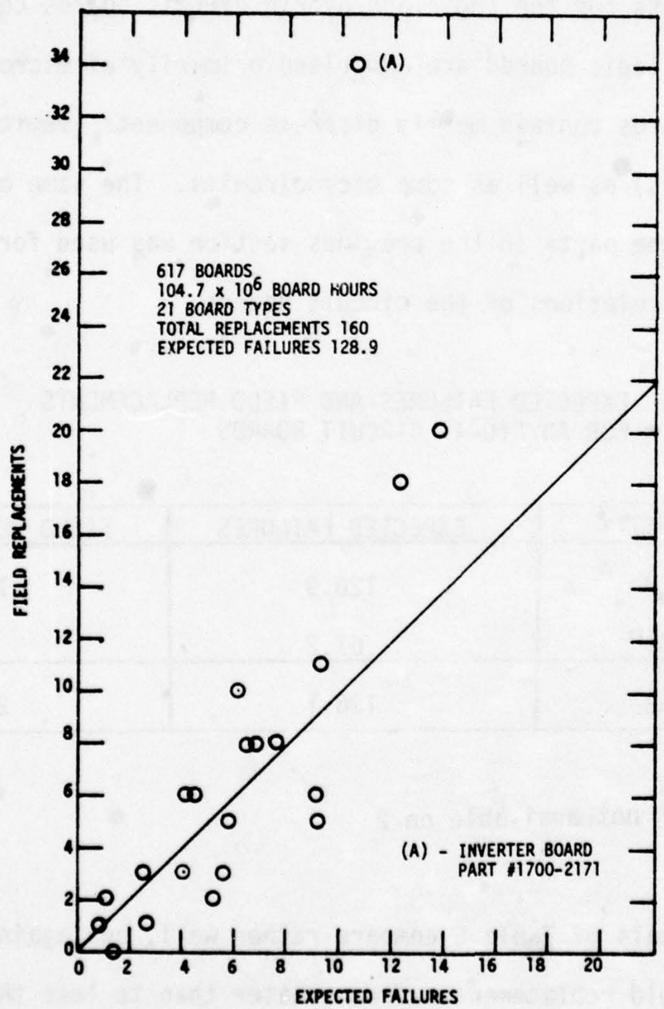

FIGURE 7. EXPECTED FAILURES VS FIELD REPLACEMENTS FOR AN/FYQ-47 LOGIC BOARDS

A total operating time of 104.697×10^6 hours was logged for the logic boards during the data collection period.

Very good correlation is evident from the plotted data. The point labelled "A" in the figure is the Inverter Board (#1700-2171). The large number of replacements for these boards is traceable partially to the QUAD 2 INPUT NAND/NOR (#1700-2510) microcircuit (point labelled "A" in Figure 5). Although the part is used extensively throughout the equipment, the problem appears at least to be localized to the Inverter Board. Again, this illustrates how the field data can be used in conjunction with the predictions, to isolate potential reliability problem areas.

The logic board data of this section can be used to illustrate two general observations regarding the use of the Air Force maintenance data for reliability assessment purposes. First, isolation of potential reliability problem areas can often only be realistically done through use of the large amounts of data which are generated through field operation. Although no single equipment is experiencing an inordinately large number of Inverter Board failures, the field data (for 31 equipments) indicate a potential reliability problem. Secondly, in some field data analysis computer programs a straight forward ranking by replacement rate is used to isolate "high-burners" or reliability problem areas. Such rankings, without comparisons using the predicted failure rates, can obviously mask important information and lead to the wrong emphasis being placed on items which intrinsically have a higher failure rate relative to other items.

4.2.2 Hybrid Boards

Figure 8 is a plot of the expected failures versus field replacements for 151 hybrid boards used in the equipment. A total of 24.62 x 10^6 board hours were logged for the hybrid boards during the data collection period.

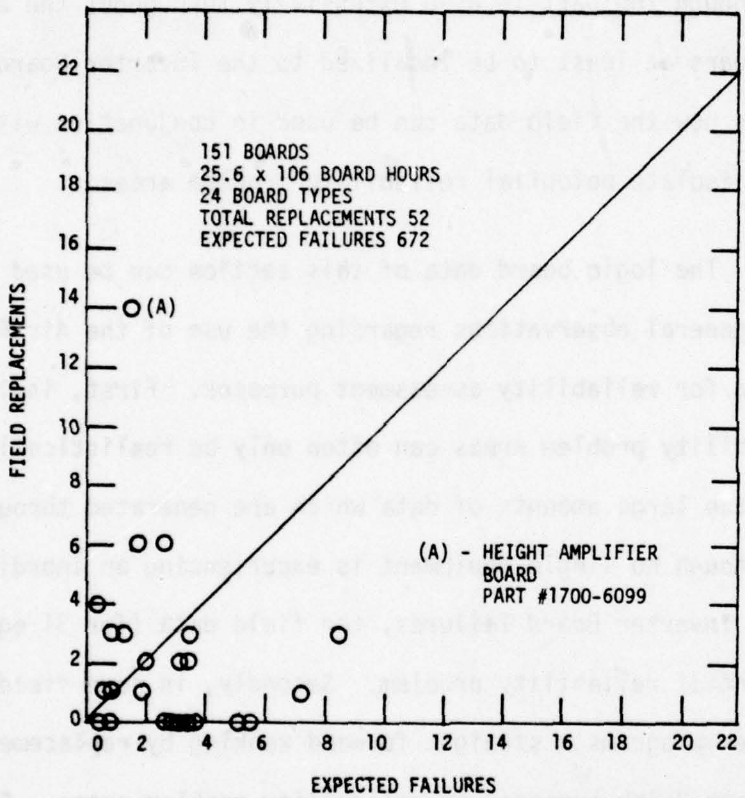

FIGURE 8. EXPECTED FAILURES VS FIELD REPLACEMENTS FOR AN/FYQ-47 HYBRID BOARDS

The poor correlation which is evident here is, of course, directly related to the poor correlation which was observed with the discrete components (transistors, capacitors, resistors). The point labelled (A) in Figure 8

is the Height Amplifier Board (#1700-6099). The relatively large number of replacements for this board is traceable to the 2N2219A transistor (Table 5 in Section 4.1.2).

If one compares Figure 7 containing the logic board data and Figure 8 containing the hybrid board data, little need is seen for obtaining additional information on the majority of logic boards, since the correlations are relatively good. However, additional failure circumstance and cause data are necessary to explain the poor correlations which are evident for the hybrid boards. One must first be fairly certain that the data are reasonably complete, that is, no omissions in reporting were made. Secondly, root cause of failure information is required, so that proper responsibility for the failures can be assigned (e.g., design, substandard parts, manufacturing processes, prediction, overstress, etc.) and corrective actions determined where required.

4.3 Summary of Findings

In evaluating the findings of the former sections (4.4.2) the R&M analysis objectives listed in Section 1 and the quality of the part level data which are available from the field must be considered. Obviously, primary failure cause information identified to the part level is essential if the objectives are to be meaningfully achieved. In fact, for most of the analysis objectives listed in Section 1 to be fully achievable, detailed failure cause information resulting from laboratory failure analyses of selected failed parts is also required. If, in making gross comparisons of reliability program derived failure rates with field estimates, there is

generally good agreement, then obtaining detailed cause information is not essential to the analyses. However, when there are major inconsistencies in the estimates either at the part, board or equipment levels, then it is essential that root cause information be obtained. Without such data, the analysis results can only be inconclusive, since the underlying data base is incomplete.

The data system conditions which are currently hindrances to attaining most of the reliability analysis objectives of Section 1 are:

(a) There are omissions in the reporting of failed part replacements in the field.

(b) Multiple part replacements are reported without any indication of the primary cause of the failure.

(c) Verification of the failure circumstance data is not normally performed (i.e., that a reported replaced part is truly a bonafide failure which caused the equipment to fail).

(d) Selective laboratory failure analysis of failed parts is not routinely performed in order to determine root cause of failure.

The Air Force maintenance data collection systems cannot be faulted for conditions (c) and (d). These conditions must be rectified through procedures established by the agency responsible for the R&M data collection and analyses. Conditions (a) and (b), however, can be rectified by implementing special data collection and handling procedures within the framework of current Air Force data systems. Further discussion of this

area will be provided in the final recommendations which are made in Section 7.2 of the report.

Some additional findings of this section are:

(a) Air Force maintenance data can be used to isolate potential reliability problem areas (Objective (b), Section 1). However, to further define the nature of the problem, additional information is required which must be developed by the group or agency performing the investigation.

(b) Data system outputs, which provide rankings by hardware replacement rates, cannot be relied upon to yield valid priority information on problem areas either in terms of cost or reliability. The reliability prediction should be used in conjunction with such rankings.

(c) Part level failure rate data derived from Air Force maintenance data systems cannot be used to verify or modify MIL-HDBK-217 predicted failure rate values (Objective (f), Section 1). This data must be supplemented by the group performing the analysis in order to be fully usable.

(d) Reliability predictions provide a baseline against which field failure rates can be compared. Use of the predictions, as a reference, enables selection of failed devices for analyses which offer the greatest return on resources expended on laboratory failure analyses.

5.0 EQUIPMENT FIELD FAILURE DISTRIBUTION ANALYSES

In order to perform the analyses of the equipment failure distribution, it was necessary to obtain additional field data. Since the data for most of the equipments were rather limited in terms of the number of failures observed, an additional nine months of data for 25 of the 31 equipments were obtained. The data for the 25 equipments were compiled in the equipment R&M Logs, and the failures were classified as described in Section 3.3.

5.1 Operating Time Between Failure Data

The operating times between failures for each equipment were required to perform the distribution analyses. Using the chronological sorts of the data, and by matching either the ESR Numbers and the Job Control Numbers, or the dates of failure, between the two sets of data, the operating times between failures were obtained. In those instances where it was not possible to accurately match the failure and operating time data, the entire equipment data set was censored from any further analysis.

The Equipment R&M Logs provided the vehicle for compiling the operating time between failure data. Further screening of the data was also performed to weed out equipment data sets which contained questionable data. For example, equipment serial number 79 (See Table 3) which had an inordinately large number of "adjustments" was censored from any further analyses. In addition, equipment serial numbers 160 and 123 of Table 3, each with previously calculated MTBF values of 2602.8 hours and 2090.6 hours respectively, were found to contain missing data. These equipments, as well

as others, where questionable data were evident, were also excluded from any further analyses. Small readjustments in the failure count were also made for some of the equipments which were to be retained for the distribution analyses. It was found that the same failures were listed in the two data sets under different coding schemes and therefore, had been doubly counted when the R&M logs were compiled.

Twelve of the 25 equipments were used for the distribution analyses. The additional data obtained for equipment serial numbers 133 and 57 were not of sufficiently good quality, so only the original data were used for these equipments. The data for the 12 equipments were plotted with cumulative failures against cumulative operating time. The total operating times only to the last reported failure for each equipment were used in the data plots and in the subsequent analyses. The data plots, which are discussed in the following section, were used as a first step in developing an analysis approach.

5.2 Plots of Cumulative Field Failures vs Operating Time

Figures 9 through 20 provide plots of cumulative failures against cumulative operating time for each of the 12 equipments. The slope of the line provided in each plot, provides a reference for the rate of occurrence of failures under the assumption of a constant MTBF equal to the predicted value of 579 hours. As can be noted, some of the equipments (e.g., serial number 71) appear to indicate an increasing failure frequency (concave upward) trend, while others (e.g., serial number 133) seem to indicate reliability growth (concave downward) trends. The majority, however,

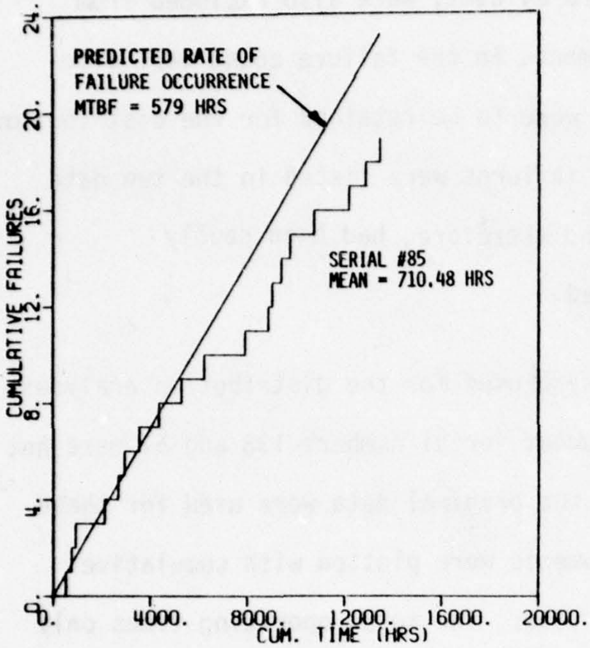

FIGURE 9

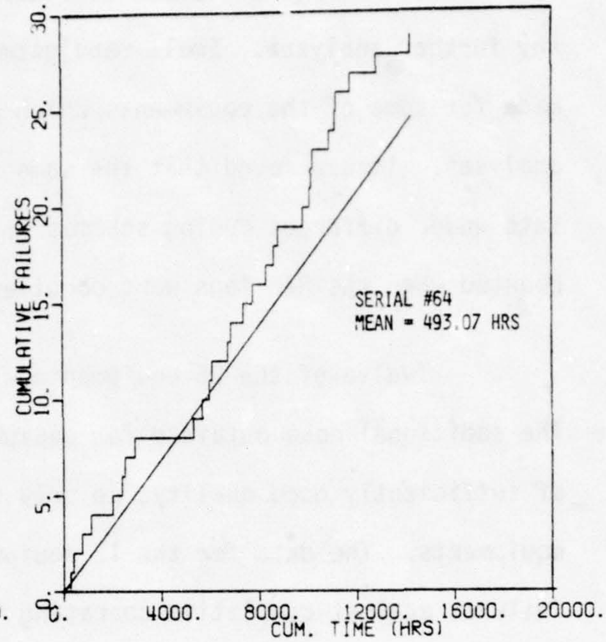

FIGURE 10

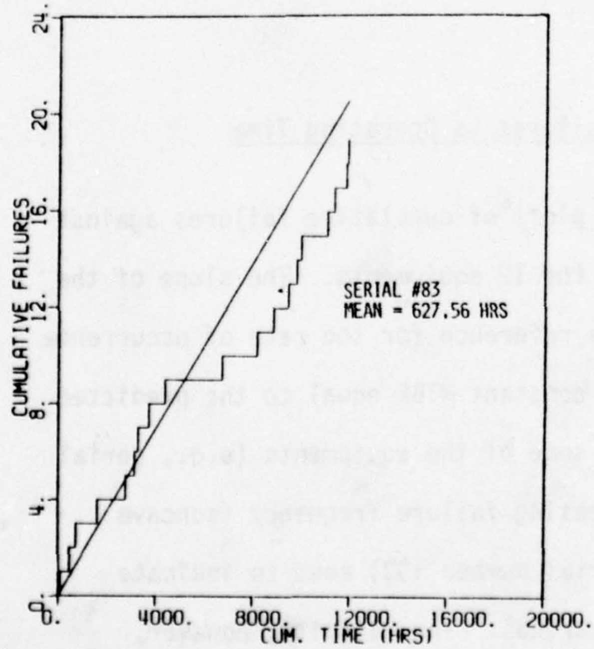

FIGURE 11

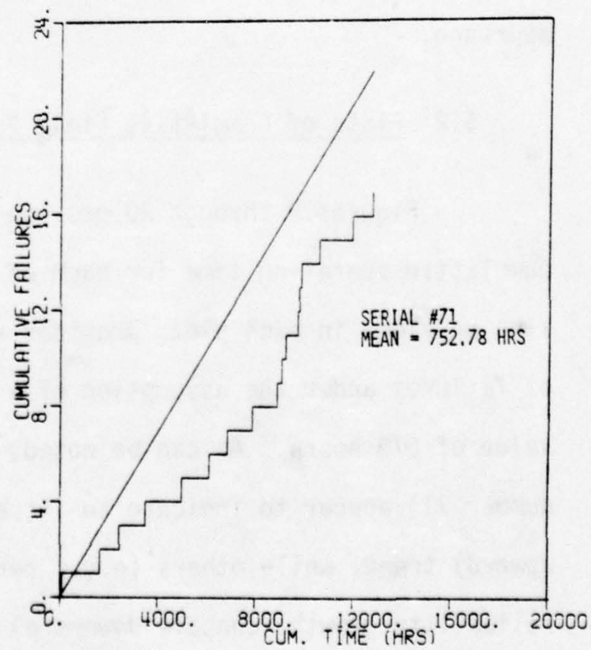

FIGURE 12

FIGURES 13-16. CUMULATIVE FAILURES VS CUMULATIVE OPERATING TIME

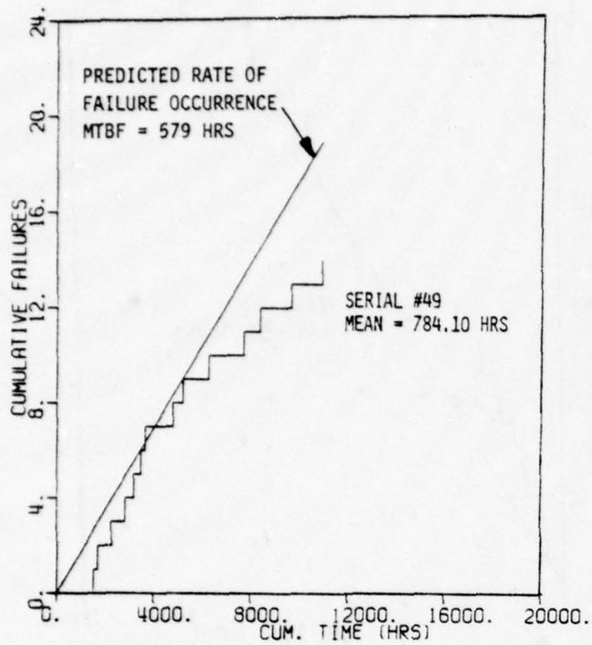

FIGURE 13

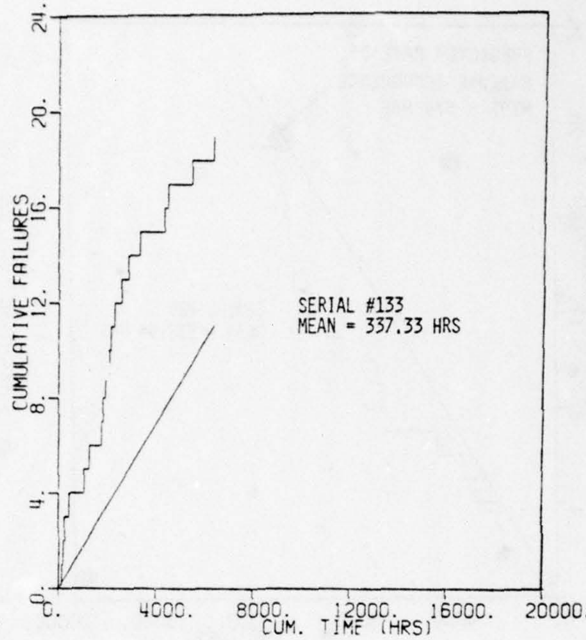

FIGURE 14

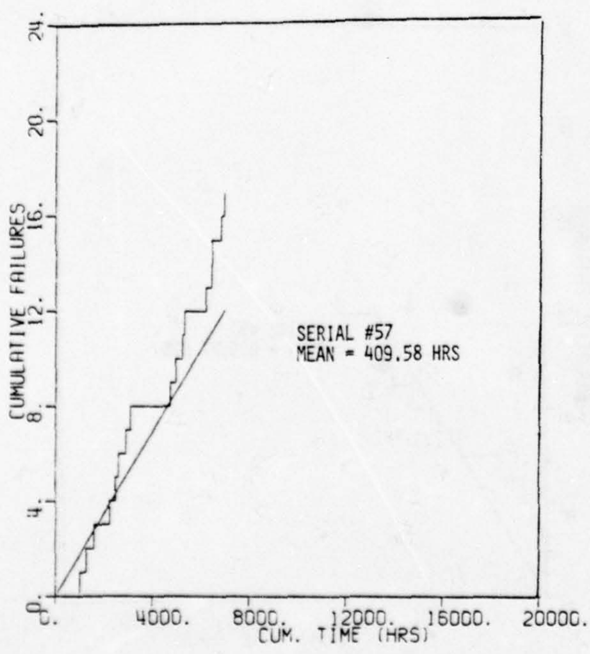

FIGURE 15

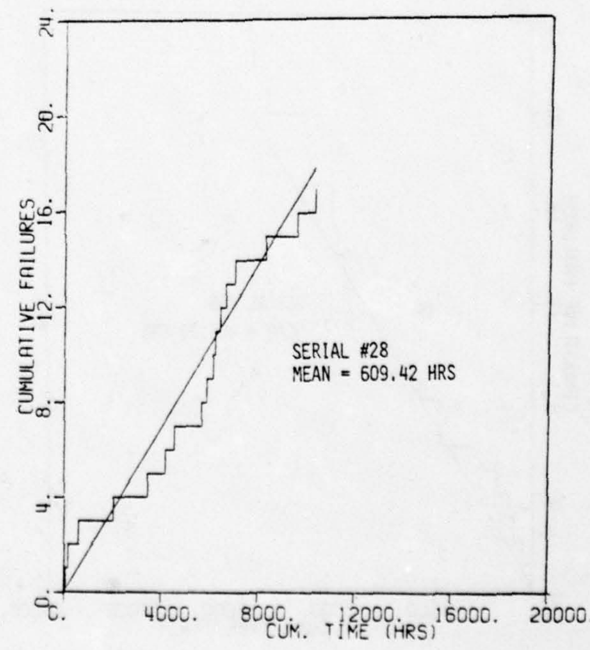

FIGURE 16

FIGURES 9-12. CUMULATIVE FAILURES VS CUMULATIVE OPERATING TIME

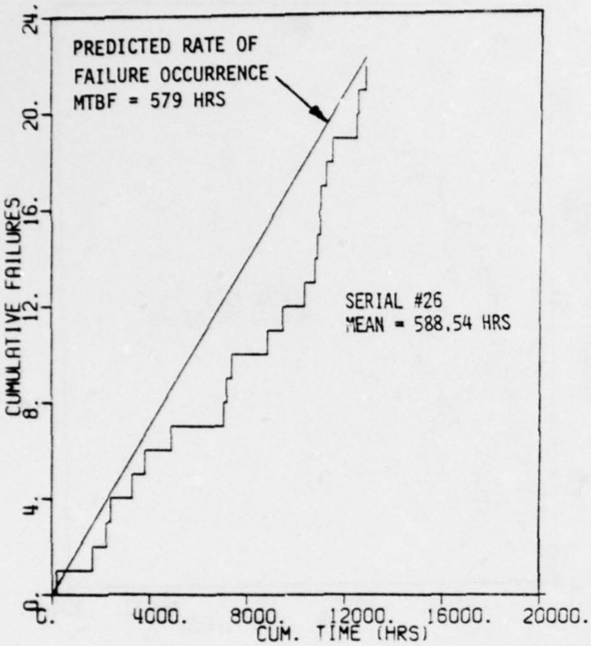

FIGURE 17

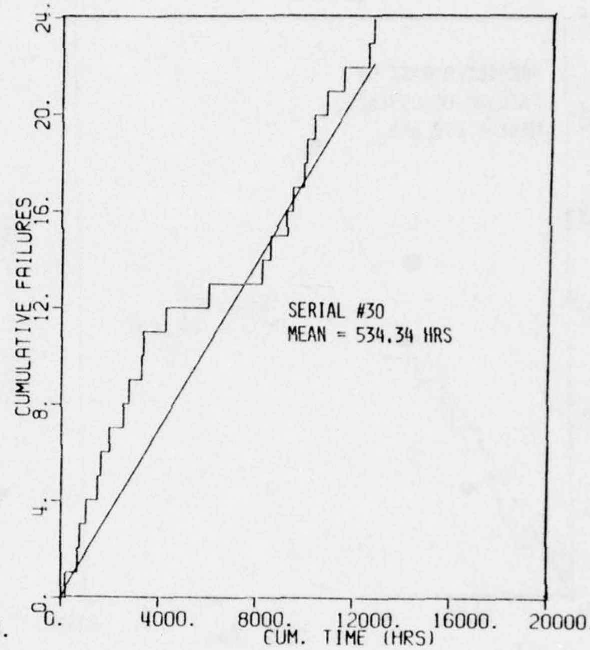

FIGURE 18

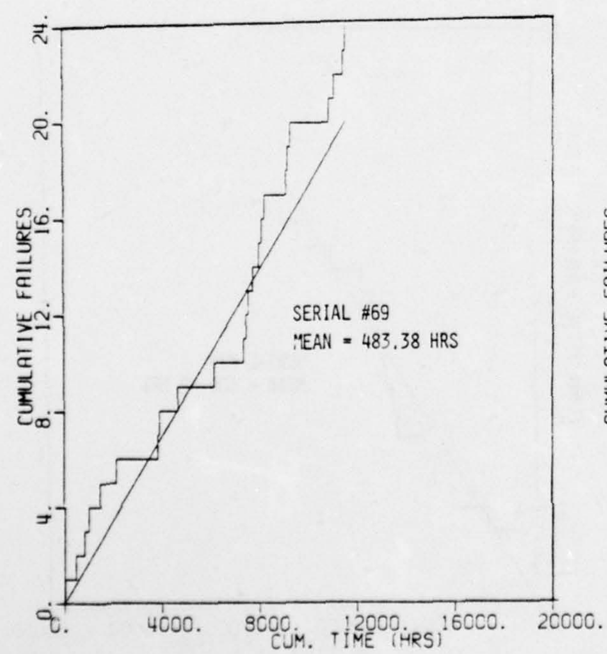

FIGURE 19

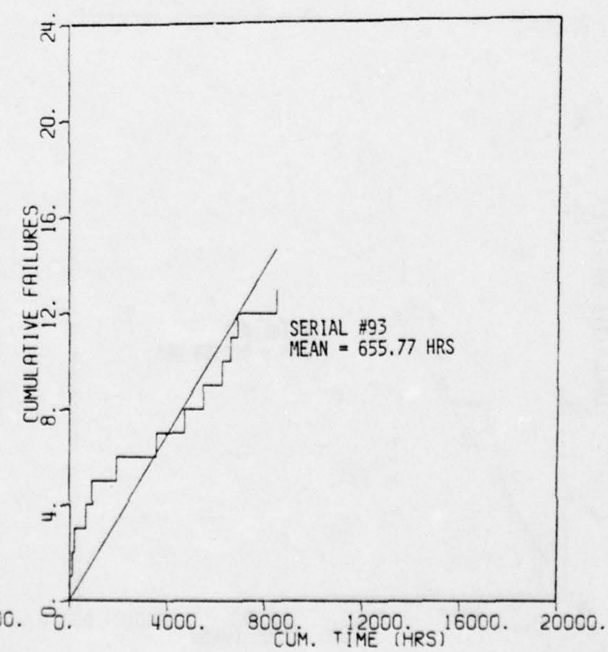

FIGURE 20

FIGURES 17-20. CUMULATIVE FAILURES VS OPERATING TIME

indicate no clear cut trends to either increasing or decreasing failure frequency with operating time. In fact, some of the equipments show cyclic patterns over the operating time periods observed. These patterns may possibly represent just random fluctuations in the failure occurrences about some average "constant" value or they may represent a long term nonconstant failure rate trend. It should be noted that the assumptions underlying the reliability prediction model discussed in Section 2.1, would imply that the equipment "failure rate" is constant. Since there was some evidence in the plotted data that nonconstant trends might be present, an analysis approach was needed to objectively assess if such trend patterns exist in the failure data.

5.3 Analysis Approach

In many analyses of repairable system failure data appearing in the literature, the equipment under study is assumed to be as good-as-new following the repair. The former assumption implies that the reliability model for the repaired equipment is identical to that of a new equipment with operating time taken at t=0 each time the equipment is repaired. Stated differently, the good-as-new assumption implies that the times between failures have identical and independent statistical distributions. Referring to the reliability prediction model used for the AN/FYQ-47, (Section 2.1) for example, said statistical distribution would be exponential with parameter equal to the sum of the failure rates of the series elements. Under the good-as-new assumption the analyses for repairable system failure data are most often done by pooling and ordering the failure times by magnitude, i.e., disregarding the original chronological sequence of the failures. The

pooled and ordered data are then analyzed, usually for exponentiality, using statistical goodness-of-fit tests.

An alternative to the good-as-new assumption is the case where, after a repair, the equipment is considered identical to an equipment which has never failed, i.e., failure times are taken from t=0 (initial installation) rather than since the last repair was made. This concept is often referred to as the bad-as-old assumption. The bad-as-old assumption implies that any parts/assemblies replaced during a given repair have the same age as the total equipment. Under the bad-as-old assumption the analysis approach would be quite different from that which might use the good-as-new assumption. The chronological sequence of the failure would have to be retained and the analysis model selected would have to address the possibility of statistically dependent and nonidentically distributed failure times.

In order to settle on an approach for the distribution analyses, a quantitative assessment of overall trend in the failure data was needed. If trends are found to be present, then the times between failure should not be treated as identical and independent observations and the pooling and ordering of the failures times would not be appropriate for the analyses. On the other hand, if no trends are found, then pooling and ordering would be permissible, and conventional goodness-of-fit tests, using various distribution assumptions, could be applied to the data.

5.4 Analysis Results

In the sections which follow, trend tests and goodness-of-fit tests are applied to the failure and operating time data for the 12 equipments.

Confidence limits for the mean-time-between-failure for each equipment are also calculated, and plots of the fitted vs empirical reliability functions for some of the equipments are provided.

5.4.1 Mann Test for Trend

The Mann Test for Trend [10] was applied to the successive failure times for each of the 12 equipments to provide an objective assessment of increasing or decreasing failure trends in the failure data. Basically, the procedure provides a test of the null hypothesis (Ho) of no trend against an alternative hypothesis (H_1) of increasing or decreasing failure frequency with operating time. If no trends in the chronologically sequenced failure times are found (i.e., the null hypothesis cannot be rejected) then it can be concluded that the good-as-new assumption is reasonable. A description of the test procedure and the results of the test follows:

Under the null hypothesis, there is no tendency for successive intervals between failure to increase or decrease. As part of the test, comparisons between successive pairs of intervals are made wherein the number of times an earlier interval is less than a later interval is counted. Given that the successive intervals for each equipment are denoted by X_1, X_2, ...Xn then a count (Tn) is made such that:

Tn = number of inequalities $X_i < X_j$, $i<j$ + one half number of comparisons $X_i = X_j$, $i<j$

(10) Mann, H.R., "Nonparametric Tests Against Trend" Econometrics, 1945, page 245-249

Mann shows that for n>10 the distribution on Tn is asymtotically normal with parameters:

$$E(Tn) = \frac{n(n-1)}{4}$$

and

$$\sigma^2(Tn) = \frac{(2n + 5)(n-1)\ n}{72}$$

where n is the number of observations

The standard normal variable

$$Zn = \frac{Tn + \frac{1}{2} - E(Tn)}{\sigma(Tn)}$$

can be used as the basis of a test of significance given reasonably large sample sizes for each equipment. A test of significance for the aggregate of all 12 equipments can be made by using the test statistic:

$$U = \frac{\Sigma(Tn + \frac{1}{2} - E(Tn))}{\sqrt{\Sigma \quad \sigma^2(Tn)}}$$

Where U is also a standard normal variable from a normal population with parameters equal to the sum of the means and variances of Tn for each of the equipments.

The test of significance is then given by:

$P(U > U_\alpha \mid Ho) \leq \alpha$ where α is the significance level.

The results of the test are provided in Table 7.

TABLE 7. RESULTS OF MANN TEST FOR TREND

S/N	N	Tn	E(Tn)	σ^2(Tn)	$\frac{Tn + 1/2 - E(Tn)}{\sigma (Tn)}$
85	19	106	85.5	204.3	1.47
64	29	218	203.0	710.5	.58
83	19	84	85.5	204.3	-.07
71	17	52	68.0	147.3	-1.28
49	14	58	45.5	83.4	1.42
133	19	120	85.5	204.3	2.45
57	17	49	68.0	147.3	-1.52
28	17	79	68.0	147.3	.95
26	22	91	115.5	314.3	-1.35
30	24	164.5	138.0	406.3	1.34
69	24	131.0	138.0	406.3	-.32
93	13	55	39	67.2	2.01
TOTALS	234	1207.5	1139.5	3042.5	

Using the data of Table 7, a calculation of:

$$U = \frac{\Sigma\ (Tn + \frac{1}{2} - E(Tn))}{\sqrt{\Sigma\ \sigma^2\ (Tn)}} = \frac{74}{55.16} = 1.34$$

for the test of significance, indicates that the hypothesis of no trend cannot be rejected at a 5% one-sided level ($U_\alpha = 1.645$) for the pooled data set. Equipment serial numbers 133 and 93, taken individually, could be rejected at the 5% level and a claim made that these equipments are exhibiting

reliability growth. Reliability growth models could be fitted to the chronologically sequenced failure times for these equipments and an appropriate goodness-of-fit test applied. These analyses were not done as part of this report, however.

Given that equipment serial numbers 133 and 93 have decreasing failure trends or for that matter, if an equipment displayed an increasing trend, the question arises as to the use of the field failure data to explain it. One might hypothesize, for the decreasing failure trend case, that failures traceable to poor workmanship (bad solder joints, board manufacture, etc.) or a bad lot of parts could have occurred. Failures traceable to such causes tend to fail early and could possibly have "escaped" production test screens. On the other hand, an increasing failure trend for an equipment could possibly be traceable to faulty manufacture, maintenance practices or to field environmental conditions which tend to accelerate failures. A review of the failure data contained in the Equipment R&M Logs for each of the above equipments, however, could not provide any clear insights into underlying causes. The data were not sufficiently detailed, nor complete, for performing such evaluations.

Distribution analysis of this type does provide a means for selecting particular sequences of failures for more detailed investigations. For example, the early sequence of failures which occurred on equipment serial numbers 133 and 93 (see Figures 14 & 20) would be good candidates for more detailed investigations on failure causes. Corrective actions on new system programs could then be taken (i.e., improved screening, burn-in etc.) depending upon the findings of such investigations.

5.4.2 Goodness-of-Fit Test for Exponentiality

Since there was not any significant evidence of trend in failure data for 10 of the 12 equipments, the failure times were ordered by magnitude for each equipment and goodness-of-fit tests were applied. Use of the exponential model was the most logical first choice. The test for exponentiality which was applied to the failure data is given in reference (11) below. The basic computing form of the test is:

$$\delta_i = \max \left[\frac{i}{n} - F(t_i; \hat{\theta}),\ F(t_i; \hat{\theta}) - \frac{i-1}{n} \right]$$

and

$$Sn = \sum_{i=1}^{n} | \delta_i |$$

where Sn is the test statistic

$F(t_i, \hat{\theta})$ - failure distribution function with mean equal to

$$\hat{\theta} = \frac{\sum_{i=1}^{n} ti}{n}$$

$i = (1, 2, \ldots n)$ is the number of failures which occur in $t \leq ti$

n = total number of failures

Critical values of Sn are tabulated in reference 11 for various levels of significance. The hypotheses of exponentiality is rejected at the $\alpha\%$ level of significance if Sn is larger than the tabulated value of $Sn_{(\alpha)}$.

(11) Mann, N.R., Schafer, R.E., Singpurwalla, N.D., "Methods of Statistical Analysis of Reliability and Life Data", 1974, Pages 336-339.

TABLE 8. RESULTS OF TEST FOR EXPONENTIALITY

SERIAL NUMBER	N	S_N (OBSERVED)	S_N (CRITICAL VALUES)	
			α = .01	α = .05
85	19	2.41	2.56	2.16
64	29	1.79	3.04	2.59
83	19	1.24	2.56	2.16
71	17	1.89	2.46	2.08
49	14	1.74	2.28	1.92
133	19	1.36	2.56	2.16
57	17	1.50	2.46	2.08
28	17	1.24	2.46	2.08
26	22	1.24	2.72	2.29
30	24	1.80	2.83	2.39
69	24	1.82	2.83	2.39
93	13	0.99	2.19	1.87

As the data in Table 8 indicate, the hypothesis of exponentiality cannot be rejected at the 1% level for all 12 equipments. Equipment serial number 85, however, can be rejected at the 5% level. A plot of the fitted vs empirical reliability function for equipment serial number 85 in Figure 23, on page 62 shows a poor fit and suggests an increasing hazard function for the failure times. The Weibull distribution would be a good next choice for use in a goodness-of-fit test for this equipment. However, for the purposes of this report, the analysis was not attempted. It is interesting

to note, that although the chronologically sequenced failure times for serial number 85 showed no evidence of trend, the ordered failure times show an operating time dependency. In addition, although equipment serial numbers 133 and 93 showed a trend toward decreasing failure frequency, the test for exponentiality did not result in rejection. The inappropriate ordering of the failure times for these equipments is the reason for the apparent anomoly. For the interested reader, further discussion of similar phenomena are provided in references 12 and 13.

5.4.3 Confidence Bounds on the System MTBF

The 90% confidence bounds on the mean were calculated for each equipment on the basis that the underlying failure distribution is exponential. Equipment serial numbers 85, 133 and 93 are also included, although the field data indicate that it is doubtful that their failure distributions are exponential.

Table 9 provides the results, showing the operating time, number of failures (N), point estimate of the MTBF ($\hat{\theta}$) and 90% confidence bounds on the mean for each equipment.

With the exception of equipment serial number 133, the confidence bounds contain both the specified and predicted values of the MTBF, thus indicating that the reliability program conducted for the AN/FYQ-47 during development and production was very effective in meeting contractual reliability requirements.

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(12) Proschan, F., "Theoretical Explanation of Observed Decreasing Failure Rate", Technometrics, Aug 1963, pages 375-382.
(13) Ascher, H., Feingold, H., "Is There Repair After Failure?", Proceedings 1978 Annual R&M Symposium, pages 190-197.

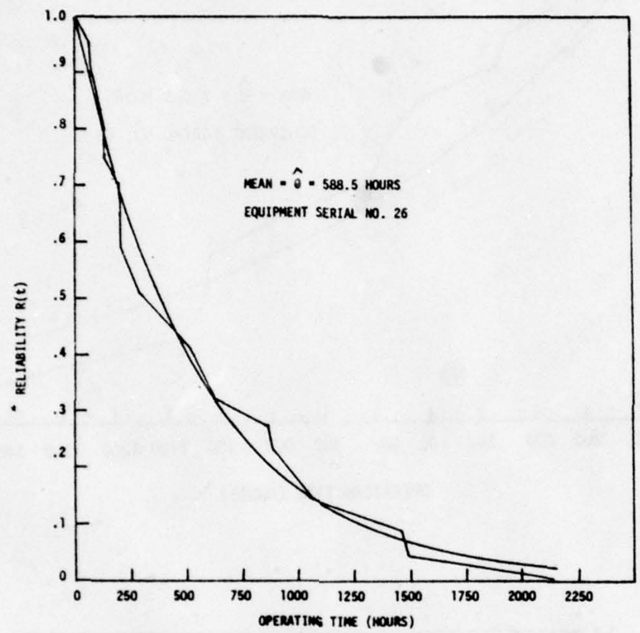
TABLE 9. 90% CONFIDENCE BOUNDS ON THE SYSTEM FIELD MTBF

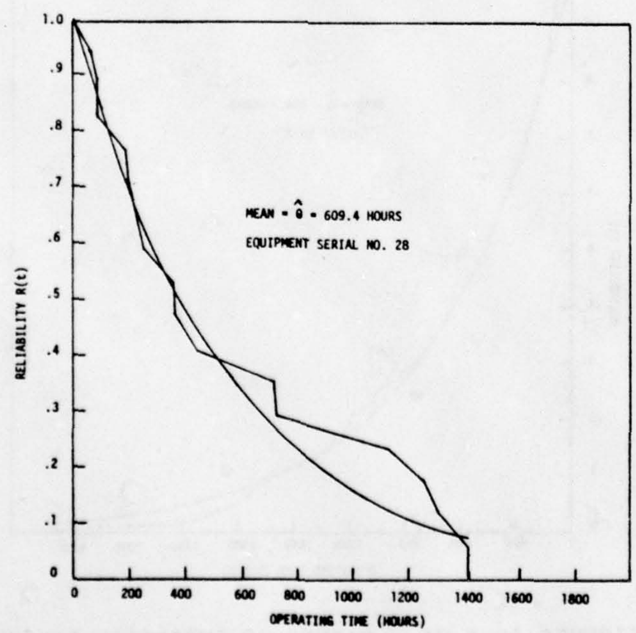
SERIAL NUMBER	OPERATING HOURS	N	$\hat{\theta}$	90% CONFIDENCE BOUNDS
85	13,499.1	19	710.5	474.7-1178.7
64	14,299.0	29	493.1	353.4- 735.0
83	11,923.7	19	627.6	419.3-1041.2
71	12,797.1	17	752.8	492.9-1289.5
49	10,977.4	14	784.1	493.8-1434.2
133	6,409.3	19	337.3	225.4- 559.7
57	6,962.7	17	409.6	268.2- 701.6
28	10,360.3	17	609.5	399.0-1043.9
26	12,947.8	22	588.5	403.5- 938.2
30	12,824.3	24	534.3	371.7- 833.5
69	11,601.2	24	483.4	336.2- 753.0
93	8,525.0	13	655.8	397.1-1202.4

5.4.4 Reliability Functions - Fitted vs Empirical

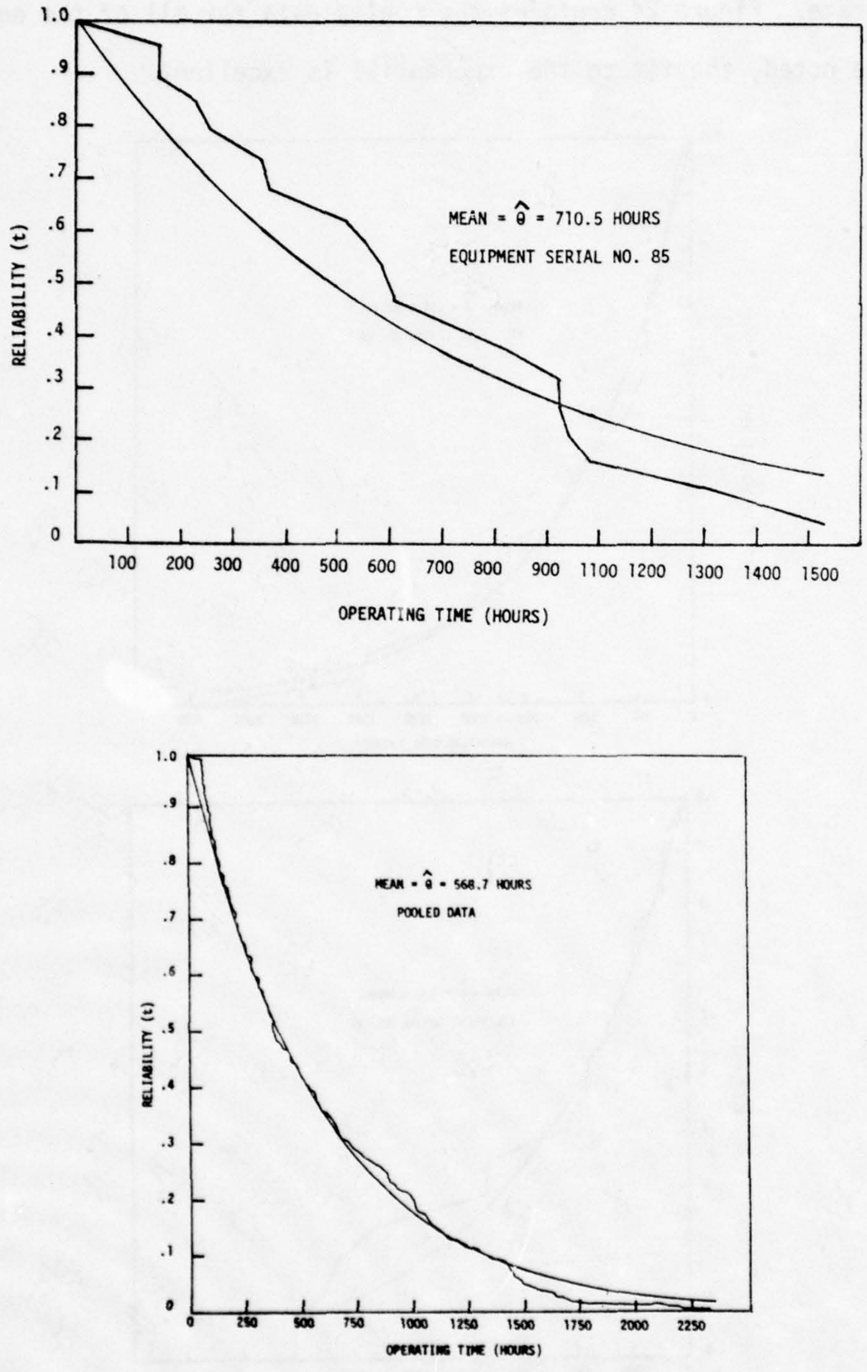
In order to illustrate the fit of the failure data to the exponential reliability function, plots of the data, showing the fitted vs empirical reliability functions, were prepared for equipment serial numbers 26, 28 and 85 in Figures 21, 22 and 23 respectively. Equipment serial numbers 26 and 28 in Figures 21 and 22 show a good fit and corroborate the results of the tests for exponentiality. As discussed earlier, the plot of the data for equipment serial number 85 in Figure 23 crosses the empirical

reliability function only once from above, thus suggesting an increasing failure rate. Figure 24 contains the pooled data for all of the equipments. As can be noted, the fit to the exponential is excellent.





FIGURES 21 & 22. FITTED VS EMPIRICAL EXPONENTIAL RELIABILITY FUNCTIONS



FIGURES 23 & 24. FITTED VS EMPIRICAL EXPONENTIAL RELIABILITY FUNCTIONS

5.5 Summary of Findings

(a) Time-to-failure data are obtainable from the field data for ground electronic equipment operating in mission environments similar to the AN/FYQ-47. Records of operating time must be maintained by the R&M data collection agency, from the date of initial installation of the equipment in the field.

(b) Analysis of the field failure distribution characteristics of an equipment provides a very useful tool for evaluating the effectiveness of the reliability assurance techniques used during design, development and production.

(c) It is essential that procedures be established for determining root causes for selected failures, in order for the distribution analyses to be fully effective in yielding corrective actions.

(d) Particular sequences of failures can be selected for more detailed investigation of causes based upon the distribution analyses. Increasing or decreasing failure frequency trends can be used as the basis for selecting failures for determination of causes and corrective actions.

(e) Serial number tracking of removed and replaced subassemblies is not normally done under current data system procedures. Although such tracking would be required for some types of analyses, the amount of record keeping involved would be prohibitive. Subassembly serial number tracking, therefore, should be done on a sampling basis to meet specifically defined reliability analysis objectives.

(f) To ensure timely identification of failure distribution trends, computer routines including trend tests, failure distribution plotting, goodness-of-fit tests, etc., should be implemented.

6.0 FIELD MAINTAINABILITY DATA ANALYSES

The downtimes recorded in the R&M Logs for each maintenance action were extracted from the AFM 65-110 (ESR) data records. Provisions for recording the start and stop times when the equipment is down, as well as coded information pertaining to the reasons for the downtime are included in the ESR data. Thus, it is possible to separate the downtime due to maintenance and administrative or supply delays. In compiling the data for the analyses, the downtimes for reasons other than for equipment maintenance were excluded. The maintenance downtimes, as reported in the data records, were then used as the basic active repair time for each maintenance action. There is no question that some "hidden" administrative or supply delay time tends to inflate the reported maintenance (repair) times. For example, a substantial number of repair times was greater than eight hours in duration. It is difficult to envision active *repair times* of 15-20 hours which do not include some delay times. Possibly the technician in reporting the data, may have found it difficult to separate active repair time from administrative or supply delays (e.g., coffee breaks, waiting for spare parts, shift changes, etc.). In any event, the data provided no bases or rationale for censoring "abnormally long" repair times. Even if the long repair times were accurately reported, there are no procedures in the data system for reporting the reasons why such long repair times occurred. In the repair time distribution analyses of the next section, the "as reported" repair times are used with all reported delay time excluded.

6.1 Field Time-to-Repair Distribution

The Lognormal Probability Distribution is often used to

characterize the repair time distribution for electronic equipment. By plotting the field repair time data on Lognormal Probability Paper, a subjective assessment of the "fit" of the distribution, as well as estimates of the distribution parameters can be obtained. Figure 25 provides a plot of the repair times for the AN/FYQ-47 malfunctions which were listed in the AFM 65-110 data. The plotted data show a good fit to the lognormal distribution. Adjustment and preventive maintenance actions were not included in the data plot since they were representative of a different task population. These data were, however, investigated in a separate analysis (not shown) without very much change in the results. The following parameter estimates were obtained from the graphical analysis.

TABLE 10. AN/FYQ-47 FIELD MAINTAINABILITY PARAMETER ESTIMATES

PARAMETER	HOURS
Mean-Time-To-Repair (MTTR)	3.9
98th Percentile	28.0
Median-Time-To-Repair	1.2

6.2 <u>Comparison with Maintainability Requirements</u>

The specified maintainability requirements for the AN/FYQ-47 were a mean-time-to-repair of .5 hours, a maximum-time-to-repair (98th percentile) of two hours with no repair taking greater than eight hours. For comparison purposes, the "requirement" distribution is shown as the dotted line in Figure 25.

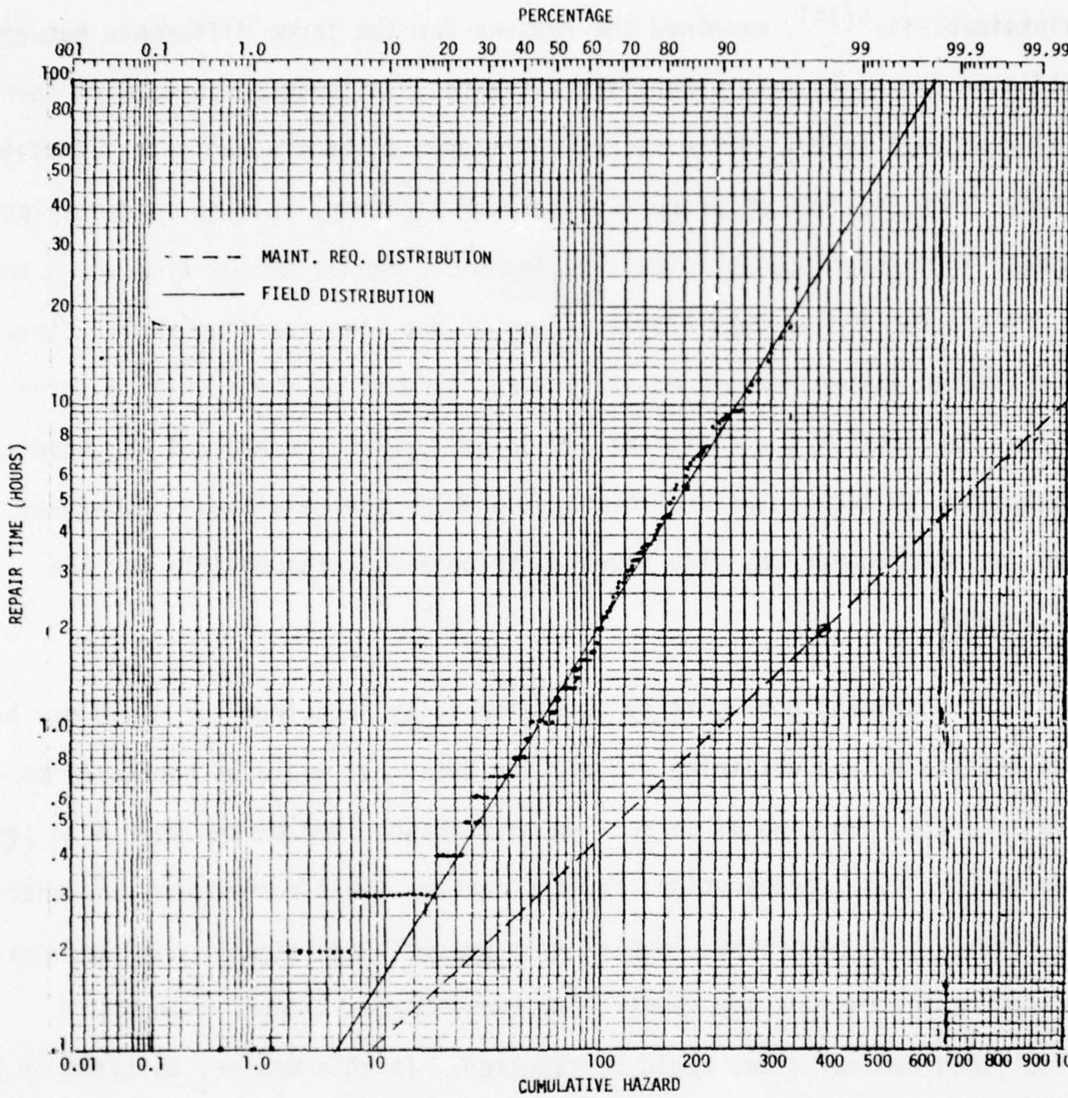


FIGURE 25. FIELD-TIME-TO-REPAIR LOGNORMAL DISTRIBUTION

There is obviously a significant difference between the contractual maintainability requirements and the field maintainability estimates. The data does not provide sufficient information to explain the disparity. A recently

completed RADC contractual study entitled, "Operational Influences on Maintainability"(14), examined the reasons for the large difference between predicted and field maintainability estimates. A large percentage of the difference was found, in the referenced study, to be traceable to operational factors such as, lack of proper tools, poor lighting, sparing inadequacies, changes in maintenance policies, and technical manual ambiguities which tend to inflate the active repair time. Some of the observed long repair times investigated in the referenced study were found to be the result of intermittent failures in the equipment and in failures of mechanical components. Degradation in technician proficiency caused by the relatively infrequent need for maintenance was also found to be partially responsible for the differences.

Obtaining good quality maintainability data from the field may be more difficult than obtaining reliability data. It would be necessary to have accurate reporting of corrective maintenance time broken down into its subelements, e.g., preparation, fault location, fault correction, and checkout times. Such reporting, coupled with possibly additional coded information indicating the reasons why repair time elements took longer than some established nominal time, would be required. In this manner, analyses of the data from different sites would enable isolating the causes for poor maintainability. Effectiveness of built-in-test equipment could be evaluated by observing the distribution of fault diagnosis times and by evaluating the reasons for large departures from expected values. The distribution of

(14) Phaller, L., Koo, D., "Operational Influences on Maintainability", July 1977, RADC Technical Report TR-77-193. (ADA042983)

fault correction times can be similarly used to evaluate the equipment design in terms of accessibility, modularity, etc., as well as the adequacy of technical manuals, tools, etc. Once the causes of poor maintainability are isolated, then corrective actions in maintainability prediction and demonstration techniques for new system programs can be taken. Air Force field maintenance data are, however, currently inadequate for performing such evaluations.

6.3 Summary of Findings

(a) Active repair time for performing corrective maintenance is obtainable from the field data by subtracting administration and supply delay times from the total downtime. However, to minimize the extent to which the active repair time is contaminated with delay time, special reporting instructions and procedures should be implemented in the field.

(b) Even if the active repair times were accurately reported, there are no provisions in the data system for reporting the reasons why abnormally long repair times occur. Improvements can be made in the procedures by specifying some nominal time (e.g., represented by the 90th percentile) beyond which the reason for the long repair time should be reported. Block 27 of the AFTO 349 form (See Appendix A) can be used for this purpose or a coding system could be used.

(c) Currently there are not any procedures in the data system for reporting corrective maintenance time broken down into its subelements (e.g., fault location, fault correction, etc.). Collection of such data, however,

would be best done on a sampling basis to meet a specific analysis objective.

(d) Analysis of the repair time distribution provides a very useful tool for evaluating the accuracy and effectiveness of the maintainability assurance techniques used during the equipment design and development.

(e) Equipment active repair time data reported from different sites can be used effectively for isolating maintainability problem areas. Not only are accurately reported active repair times necessary, but in addition, accurate knowledge of failure frequency is also required.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Recently, there have been proposals and recommendations for improving the quality of Air Force field maintenance data for use in field R&M assessments. The proposals have ranged from: (a) scrapping entirely the AFM 66-1 system and starting anew, (b) modifying the data collection forms and procedures to include needed R&M data elements, (c) using special dedicated R&M data collection "tiger teams" at the field sites, and (d) implementing "real-time" computer processing of the maintenance data, coupled with remote access and query capability by user agencies. Although improvements have been made in the data systems as a result of some of the recommendations, there remains a need for good quality field R&M data.

Underlying the conclusions and recommendations to be made as a result of this study are three basic premises. First, Air Force maintenance and status reporting systems will continue to be used in their present form. It should be recognized that these data systems were not designed for R&M analysis purposes. There are many primary users of the data (logistics and maintenance managers) who do not have the same analysis objectives as the R&M community does. Second, Air Force maintenance technicians are primarily motivated to repair the equipment and not to discern root causes of failure when they are confronted with competing failure cause circumstances. In addition, field technician personnel are already burdened with large amounts of paperwork and are justifiably motivated to "fix" the equipment and not to document failure details. As a result, failure data reported from the field tends to be "muddy" at best, and in need of validation. Third, it is more desirable,

if not essential, to have good quality R&M data on a few selected systems, than the mass of generally incomplete and fragmented R&M data which currently exists for most fielded systems.

7.1 Conclusions

(a) One of the major conclusions of the study is that the use of Air Force maintenance data systems, coupled with the information provided in TOs, Work Unit Code Manuals, etc., provide much of the data needed to perform field R&M assessments. In fact, the levels of analysis detail attained in this study, go much further than what was thought possible. However, the data systems fall short in certain key areas, which tends to degrade the potential usefulness of the data for achieving R&M analysis objectives. In addition, unless a way is found to correct the deficiencies, further developments and use of this very valuable R&M data source are not likely to occur.

(b) The most serious failing of Air Force data systems for use in reliability assessment is the lack of primary failure cause information identified to the lowest level (part) of assembly. The reason for the former condition stems partially from incomplete reporting of failure data from the field. However, even if the reporting were reasonably complete, there would still be a need for verifying the failure circumstance data to ascertain that a bonafide system failure had occurred and that the primary cause has been properly identified.

(c) Laboratory failure analysis of selected failed parts is required to further pinpoint failure causes so that analysis objectives might

be fully achieved, i.e., responsibility for the failure is assigned and corrective actions determined.

(d) The reliability design prediction and the reliability model are essential elements of the field reliability assessment program. Use of the model enables a proper accounting of the field failures to be made. The predictions provide a baseline against which field failure rates can be compared. Without the prediction data, items which have abnormally high or low failure rates cannot be properly identified. In those cases where the prediction data may be suspect, comparisons of failure rates can be made for the same item used in different equipment or circuit applications. Thus, use of the prediction data also provides a basis for modifying prediction procedures which might have resulted in overly optimistic or pessimistic failure rates.

(e) The equipment technical orders, work unit code manuals, and illustrated parts breakdown are also required for the field R&M assessment program. Hardware identifications which are made between the early design and field deployment are evolutionary in nature. As a result, there are part numbers assigned by the equipment manufacturer, generic part identifications assigned by part vendors, and work unit codes assigned by the government. Resolving hardware identification ambiguities in the data is one of the most time-consuming and difficult tasks in performing field R&M evaluations. The use of part, board, and assembly cross identification lists are required to edit and validate the data prior to processing and analysis.

(f) Special data reporting and processing procedures are required

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for those systems for which R&M assessments are desired. Said procedures should remain within the framework of the current data systems so as not to result in additional paperwork for the field technician nor cause disruption in existing data processing programs and to other data system users.

(g) R&M data collected from the field must be supplemented with additional inputs developed by the group or agency which is performing the data collection and analyses.

7.2 <u>Recommendations</u>

(a) A sampling plan should be developed for those equipments in the field for which R&M assessments are desired. The plan should be based upon such factors as: the total population of equipments in the field, expected failure frequency, equipment part count and the need for obtaining specific information pertinent to defined analysis objectives.

(b) The equipments to be sampled in the field should be "red flagged" so that field personnel know that special data collection and handling procedures will be in effect for a specified period of time.

(c) An AFSC Supplement to AFM 66-1 and AFM 65-110 should be prepared to augment data collection and handling procedures for those equipments to be sampled for field R&M assessments.

(d) The AFSC supplement should provide procedures and guidance for the special reporting and handling of field R&M data which include:

(1) Emphasis on complete, accurate and timely reporting of

all failure circumstance data on existing data collection forms.

(2) The need for accurate identification of primary failure cause information to the lowest level of assembly.

(3) The use of narrative descriptions of the failure and repair action in the blocks provided on the existing forms

(4) The accurate use of coded information (additional codes, when discovered codes, action taken codes) on the forms so that proper accounting of the failures can be made.

(5) Provisions for obtaining a copy of the raw data forms from the field on a timely basis.

(6) Provisions for obtaining failed devices from the field for failure analyses.

(7) Procedures for recording coded maintainability information, in the AFM 65-110 data, pertaining to subtask times, (fault location, fault correction, preparation, etc.) of corrective maintenance time. In addition, procedures for recording the reason for "abnormally long" repair times (e.g., greater than the specified 90th percentile) should be provided in the supplement.

(e) Communication procedures (TWX, telecopier, etc.) between supervisory field maintenance personnel and the group or agency performing the R&M analyses should be established.

(f) Each of the failures reported from the field should be validated and verified by the group responsible for performing the analyses prior to data processing. Validation would ensure that correct hardware identification and complete failure documentation has been made. Verification implies identifying that a bonafide failure has occurred and that the correct primary cause has been determined. Such verification should perhaps best be done on as near a real time basis as possible through communication where necessary with field personnel. The alternative to this approach is to attempt to reconstruct failure circumstances which might have occurred 3-6 months in the past.

(g) Computer processing of the validated and verified R&M data should be done with provisions for updating, with additional information (e.g., failure analysis results) which may become available later.

(h) Computerization of analysis tasks such as calculation of expected failures, trend tests, goodness-of-fit tests, plotting of failure data, etc., should be done so as to facilitate timely preliminary analysis and the selection of failed parts for more detailed investigation of failure causes.

(i) R&M program data (prediction, demonstration, etc.), the parts count and the technical and work unit code manuals should be available for the R&M assessment program.

Figure 26 illustrates the various elements and the data flow inherent to the recommendations made above.

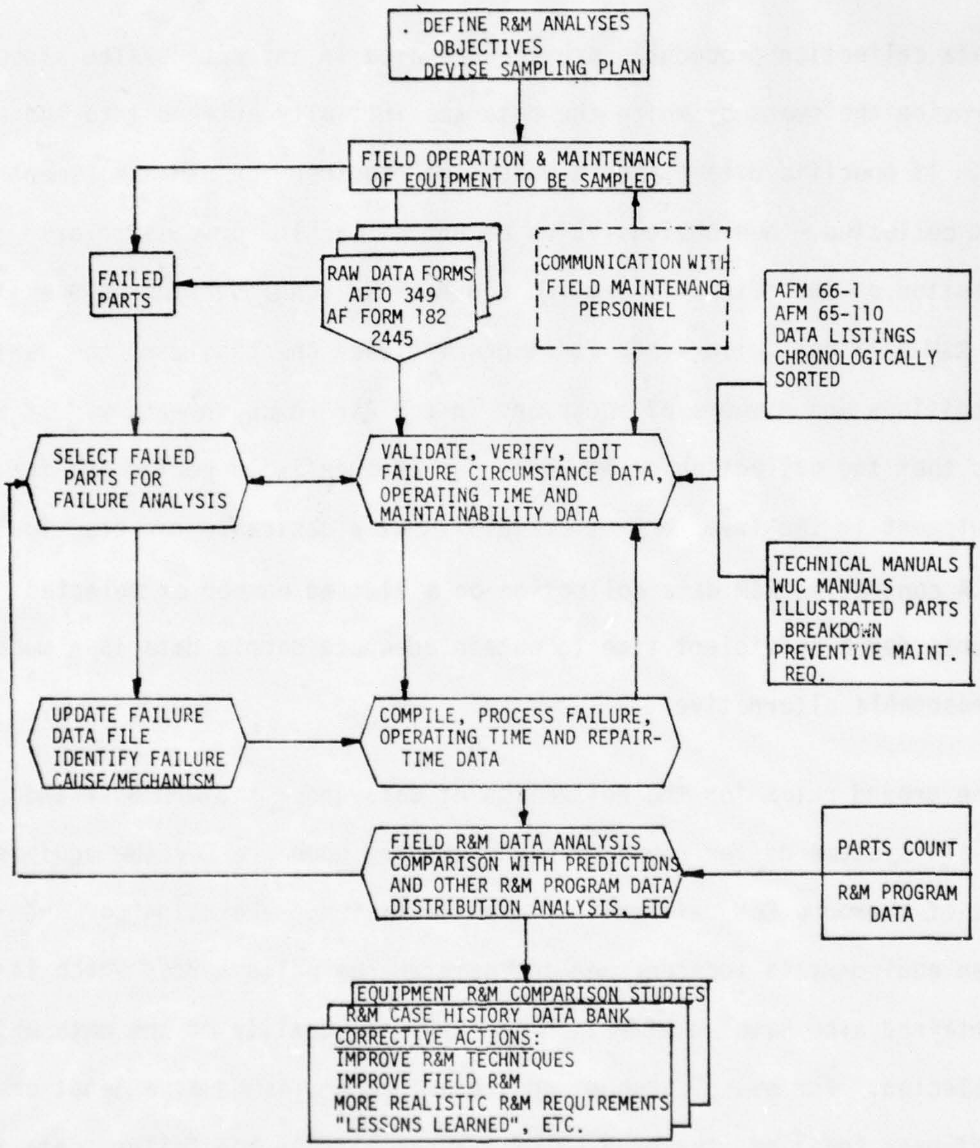

FIGURE 26. RECOMMENDED FIELD R&M DATA COLLECTION AND ANALYSIS PLAN

AD-A069 920 ROME AIR DEVELOPMENT CENTER GRIFFISS AFB NY F/G 9/5
THE USE OF AIR FORCE FIELD MAINTENANCE DATA FOR R AND M ASSESSM--ETC(U)
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UNCLASSIFIED RADC-TR-79-103 NL

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APPENDIX A

A.1 AIR FORCE MAINTENANCE DATA COLLECTION

Data collection procedures are the key area in any data system since they provide the means by which the data are initially entered into the system. If specific data elements which are required for R&M assessment are not collected, then obviously, no amount of machine processing or manipulation of the data will provide the desired results. The complexity of the R&M data collection task is staggering when one considers the variety, use conditions and numbers of equipment in the Air Force inventory. It is obvious that the collection of R&M data for an indefinite period and for all the equipment in the inventory is certainly not a desirable nor practical goal. A controlled R&M data collection on a limited number of selected equipments for a sufficient time to obtain adequate sample data is a much more reasonable alternative.

The ground rules for the collection of data under the AFM 66-1 and AFM 65-110 systems differ considerably depending upon whether the equipment is part of a ground CEM, aircraft or missile system. The using command in which an equipment is located, and the maintenance policy under which it is maintained also have an effect on the type and quality of the data which are collected. For example, when repairs are accomplished at a depot or some off-base location, the problem of traceability in the failure data to lower equipment levels is certainly more difficult, if not impossible to achieve. The problem of failure and operating time data collection is much more complicated for an avionic equipment which may be operated periodically

in various aircraft than it is for a ground equipment operating 24 hours per day at a fixed location. The discussion of data collection forms below are provided in the context of their use in the ground equipment environment.

A.1.1 AFM 66-1 Maintenance Data Collection Forms.

Figures A1 and A2 are front and reverse side copies of the AFTO Form 349, "Maintenance Data Collection Record", which is the basic source document for the maintenance data collection (AFM 66-1) system.

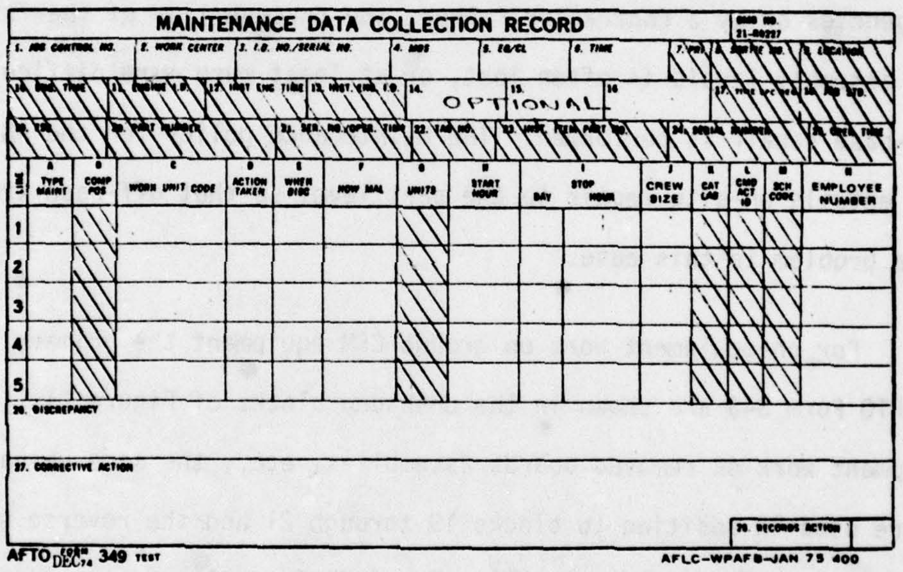


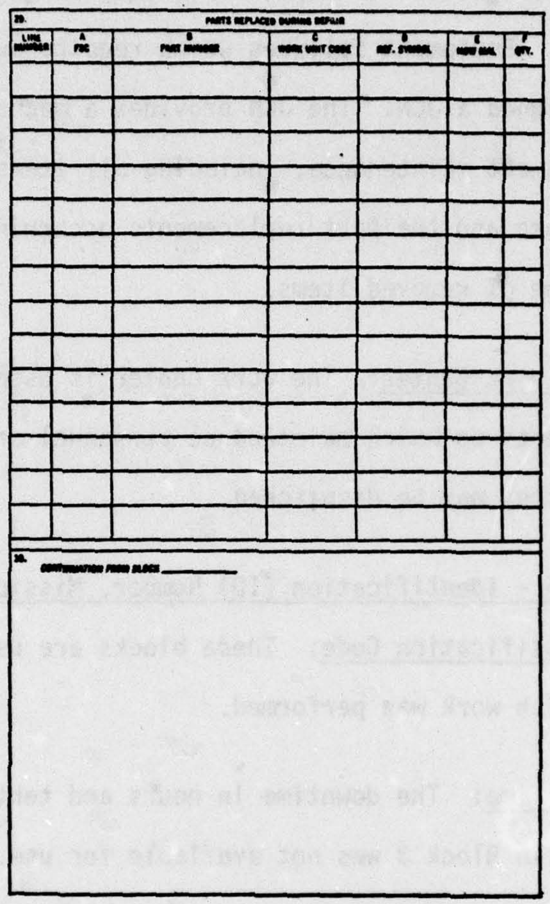
FIGURE A1. AFM 66-1 MAINTENANCE DATA COLLECTION RECORD (AFTO 349)

The AFTO Form 349 is a multi-purpose form which is used to record various maintenance actions including inspections, support general work, time-change removals and unscheduled maintenance. The recording

procedures are divided into two categories identified as on-equipment and off-equipment maintenance. On-equipment maintenance consists of maintenance actions on complete end-items of equipment (e.g., AN/FYQ-47). Remove and replace actions, adjustments and calibrations are reported as on-equipment actions. In-shop maintenance actions involving replacement of parts on sub-assemblies or circuit boards are identified as off-equipment maintenance.

It is important to note, that since the AFM 66-1 is a base level maintenance management system, little provision is made for recording off-equipment maintenance data for repairs accomplished at a depot, special repair agencies or by a contractor. Thus, the traceability of the failure to lower assembly levels is often lost, or at least much more difficult, when off-base repair is performed. The maintenance policy for the AN/FYQ-47, however, entails on-site repair to the part level so that off-base traceability was not a problem in this case.

For on-equipment work on ground CEM equipment the primary entries on the AFTO Form 349 are shown in the unshaded blocks of Figure A1. For off-equipment work on removed boards assemblies, etc., the same unshaded blocks are used in addition to blocks 19 through 21 and the reverse side of the Form Block 29 (see Figure A2). The AFTO Form 350, (not shown) is a two-part form that is attached to boards or components that are removed during on-equipment maintenance. The form serves as an identification and status tag which provides the information required in completing the AFTO 349 for off-line work.



29. PARTS REPLACED DURING REPAIR						
LINE NUMBER	A FSC	B PART NUMBER	C WORK UNIT CODE	D REF. SYMBOL	E HOW MAL	F QTY.

30. CONTINUATION FROM BLOCK ____________

FIGURE A2. AFM 66-1 MAINTENANCE DATA COLLECTION RECORD (REVERSE SIDE AFTO 349)

A description of the data elements of the AFTO Form 349 is given below:

Block 1 - Job Control Number (JCN): The JCN consists of seven characters, the first three characters are the Julian date, and the last four are used to identify jobs which are assigned a monthly job sequence number (e.g., the first job of the month occurring on 10 Feb would have

the JCN 0410001). The definition of a "job" falls into four basic categories of work, equipment malfunctions, inspections, support general work and time-change requirements. Equipment failures which require unscheduled corrective maintenance are assigned a JCN. The JCN provides a means to tie together all on and off-equipment maintenance, including all items replaced on-line to correct the failure and the part replacements occurring during off-equipment maintenance of removed items.

Block 2 - Work Center: The work center is used to identify organizational elements to which maintenance personnel are assigned or locations to which they may be dispatched.

Blocks 3-5 - Identification (ID) Number, Mission-Design-Series (MDS) Equipment Classification Code: These blocks are used to identify the equipment on which work was performed.

Block 6 - Time: The downtime in hours and tenths of hours that the item identified in Block 3 was not available for use.

Column A - Type Maintenance Code: The type maintenance code consists of one character and is used to identify the type of work that was accomplished such as scheduled or unscheduled maintenance.

Column C - Work Unit Code: The work unit code consists of five characters, and is used to identify the system, subsystem or circuit card on which maintenance is required. The first two positions of the work unit code identify the functional system (e.g., CA000 represents the FYQ-47 Central Processing System). The third and fourth positions identify sub-

systems or major assemblies as applicable (e.g., CAA00 represents the OL-46/FYQ-47 Data Programming Group, CAB00 represents the AN/FYA-83 Indicator Group, and CAAA0 represents the Height Finder Module). The fifth position of the work unit code normally identifies repairable items (e.g., CAAAA represents the 8-Bit Ladder Board). The work unit codes are published in work unit code manuals for each weapon and support system.

Column D - Action Taken: The "Action Taken" code consists of one character and is used to identify the maintenance action that was taken such as remove and replace. A list of authorized "Action Taken" codes is contained in the work unit code manual for the equipment.

Block E - When Discovered Code: The "When Discovered" code consists of one character and is used to identify when a failure was discovered such as during inspection or equipment operation. A list of authorized "When Discovered" codes is contained in the work unit code manual for the equipment.

Block F - How Malfunctioned Code: The "How Malfunctioned" code consists of three characters and is used to identify how the equipment, assemblies or board malfunctioned. A complete list of "How Malfunctioned" codes are contained in the work unit code manual for the equipment.

Columns H and I - Start/Stop Day/Hour: The day and hour (to the nearest five minutes) that the job described on the line was started and stopped.

Column J - Crew Size: The number of personnel involved in the job described on the line.

Column N - Man No.: A five position locally assigned man number consisting of the first letter of his last name in the first position and the last four digits of his social security number.

Blocks 26 and 27 - Discrepancy and Corrective Action: A description of the discrepancy or work to be performed and the action taken to correct the problem. Provision is made for continuation of any narrative in Block 30 on the reverse side of the form.

Block 29 - Parts Replaced During Repair: This block is used to record the identification of parts replaced during repairs. Specific entries are outlined below:

Line Number Column: The line number from the front side of the form that identifies the item to which the parts replacement data recorded in Column H through F of Block 29 is related.

Column A - Federal Supply Class: The Federal Supply Class Code which applies to the part being replaced.

Column B - Part Number: The manufacturer's part number of the part being replaced.

Column C - Work Unit Code: The work unit code of the replaced part (if assigned). If the replaced part does not have an assigned work unit code the next higher assembly work unit code is entered.

Column D - Reference Symbol: The reference designation which provides the position within the circuit of the replaced part.

Column E - How Malfunctioned: The "How Malfunctioned" code which describes how the part that was replaced malfunctioned.

Column F - Quantity: The quantity of parts in each line entry that were consumed in making the repairs.

A.1.2 AFM 65-110 Data Collection Form

Figures A3 and A4 respectively illustrate the AF Form 182, "Equipment Status Report", and the AF Form 2445, "Job Control Document" which are used for utilization and status reporting for ground CEM equipment in the AFM 65-110 system.

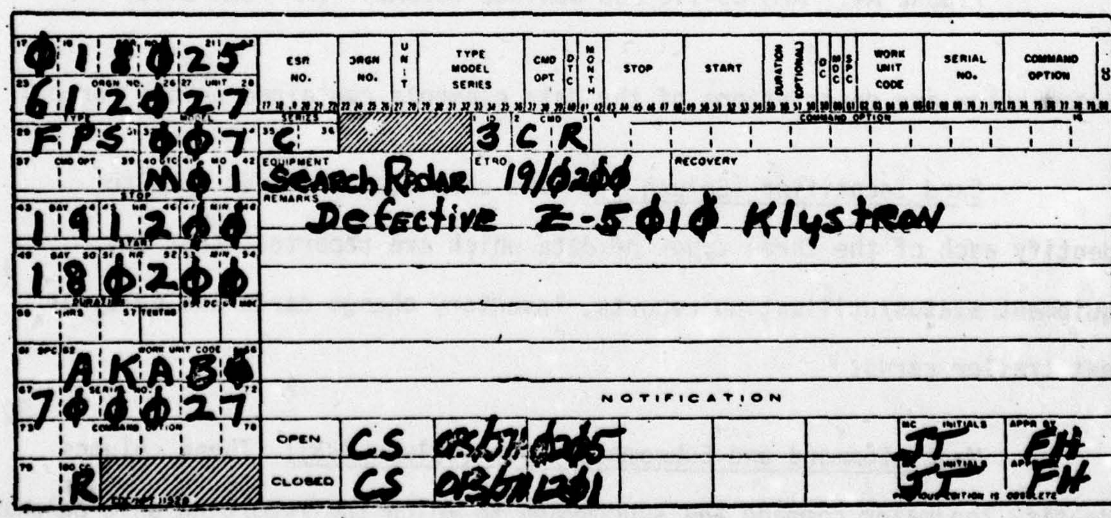
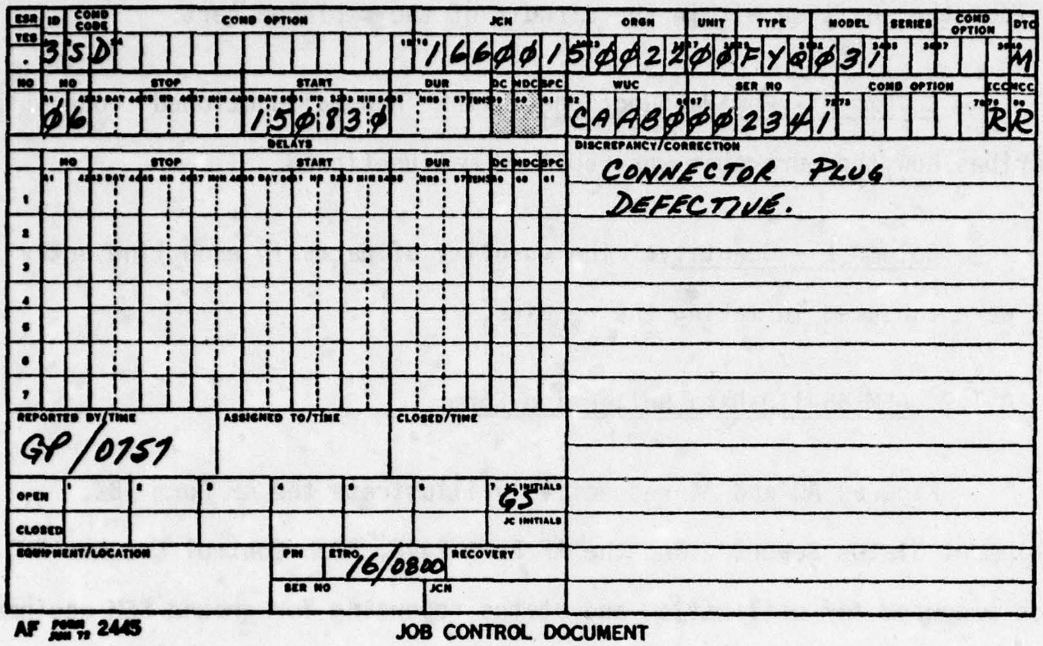


FIGURE A3. AFM 65-110 EQUIPMENT STATUS REPORT (AF FORM 182)


ESR | ID | COND CODE | COMD OPTION | JCN | ORGN | UNIT | TYPE | MODEL | SERIES | COMD OPTION | DTC

YES

. 3 5 D 1 6 6 0 0 1 5 0 0 2 2 0 0 F Y 0 0 3 1 M

HO | NO | STOP | START | DUR | DC | MDC | SPC | WUC | SER NO | COMD OPTION | ECC | MCC

0 6 1 5 0 8 3 0 CA A B 0 0 0 2 3 4 1 R R

DELAYS

NO | STOP | START | DUR | DC | MDC | SPC

1 2 3 4 5 6 7

DISCREPANCY/CORRECTION

CONNECTOR PLUG DEFECTIVE.

REPORTED BY/TIME GP/0757

ASSIGNED TO/TIME

CLOSED/TIME

OPEN | 1 | 2 | 3 | 4 | 5 | 6 | 7 JC INITIALS GS

CLOSED | JC INITIALS

EQUIPMENT/LOCATION | PRI | ETRO 16/0800 | RECOVERY

SER NO | JCN

AF FORM JUN 73 2445

JOB CONTROL DOCUMENT

FIGURE A4. AFM 65-110 JOB CONTROL DOCUMENT (AF FORM 2445)

Listed below are descriptions of the data elements contained on the forms.

Card Identifier (Column 1): The card identifier is used to identify each of the three types of data which are reported, that is, equipment status/utilization reports, inventory change cards and delay or text trailer cards.

Major Command and Subcommand Code (Column 2-3): These columns identify the major command and subcommand to which the reporting unit belongs.

Local Use (Column 4-14): These columns are available for use locally by the reporting units.

ESR No. (Columns 15-22): The ESR number consists of seven characters, the first three numbers are the Julian date and the last four are a locally assigned number beginning each day with 0001. Column 15 is used to modify the JCN on the AFTO 349.

Organizational Number (Columns 23-26): The applicable code which identifies the site/organization at which the equipment is located.

Subcommand Number (Columns 27 & 28): The subcommand number is entered to identify the subcommand to which the unit is assigned.

Type Model Series (Columns 29-36): The identification of the equipment being reported on.

Functional Position (Columns 37-38): The functional position is used to identify an individual item where more than one item is located at a single reporting unit.

Channel (Column 39): This data element is used to identify redundant channels in dual channel equipment and to identify other major reportable components in complex end-items.

Downtime Code (Column 40): The downtime code consists of one character and is used to indicate the reason for the downtime.

Month (Columns 41-42): The month in which the status change occurred.

Stop (Columns 43-48) Start (Columns 49-54): The date and time (in hours and minutes) that the status change incident was started and stopped.

Example: An equipment went down at 0815 on the 22nd day of the month and was returned to operation at 0900. Entries would be made as follows: 220815 and 220900 in the appropriate columns.

Duration (Columns 55-58): The duration of the downtime calculated in hours and tenths.

Delay Code (Column 59): This data element is used to identify the nature and length of any delay encountered in returning an equipment or channel to an operational condition.

Multiple Delay Code MDC (Column 60): The sequential order of delays in returning an equipment to operational condition is identified by use of the multiple delay code.

Special Code (Column 61): This special code is used to identify continuation cards of active incidents which are carried over from a previous reporting period. It is also used as a code to identify continuation cards where an ESR has been closed and reopened for some other reason.

Work Unit Code (Column 62): Used to identify the lowest work unit coded assembly which caused the malfunction.

Serial Number (Column 67-72): Used to identify a particular end item by its assigned serial number.

Subsystem Outages (Columns 73-78): These entries are used to indicate the effects of an equipment outage on the unit's capability to perform its mission. An entry in these columns indicate that the flow of data for a particular subsystem has been interrupted. For example, a failure in the FYQ-47 can interrupt the flow of data in three subsystems search (Column 73), height (Column 75) and SIF (Column 76).

Equipment Condition (Column 79): Entries in this column are used to identify the operating condition of the equipment being reported on. If an equipment end item is not fully operational, but is still able to provide some usable data, an "N" is entered in this column. If the equipment end item is unable to perform its function, a "G" is entered in this column.

Mission Capability (Column 80): This entry is used to identify the effect of an ESR on a reporting unit's capability to perform its mission. If there are any subsystem outages (entries in Columns 73-78) an "R" is entered. If Columns 73-78 are blank an "A" is entered.

APPENDIX B

REQUIRED R&M DATA ELEMENTS

Listed in Table B1 are the R&M data elements required for field R&M assessment. Data elements 1 through 33 are those required for reliability assessment, and data elements 34 through 39 are the additional elements needed for maintainability assessment.

Not all of the listed data elements are directly obtainable from the data collection forms, but many can be obtained through use of the work unit code and technical manuals. Comments are provided below pertaining to those data elements which can be obtained in this manner.

Some of the listed data elements are contained on the forms, but are *not processed into the data system.* These data elements are used locally by field personnel at the base level. Comments regarding these data elements are also provided in the subsequent discussions.

The data elements listed with an asterisk are those for which the agency or group performing the R&M analyses must provide additional input. These data elements refer to the verification and proper identification of the primary cause of the failure. Data element number 33 is the most seriously lacking piece of data since it is essential for reliability assessment.

Some of the required data elements are contained in existing data forms, but procedural changes are required so that the data can be more effectively used for R&M assessments. These data elements are identified

TABLE B1. R&M DATA ELEMENTS

1. Report Number
2. Original Report Number
3. Reporting Activity
4. Work Center
5. System Type Model, Series
6. System Serial Number, Manufacturer
7. Equipment Type, Model, Series
8. Equipment Serial Number, Manufacturer

*9. Failed Item Part Number
*10. Failed Item Reference Designation
*11. Failed Item Name
*12. Failed Item Manufacturer

13. Failed Item Serial Number
14. Next Higher Assembly Part Number
15. Next Higher Assembly Serial Number
16. Next Higher Assembly Name, Manufacturer
17. Replacement Part Number, Serial Number
18. Replacement Part Manufacturer, Reference Designation
19. Date of Malfunction
20. Type of Maintenance Code
21. Narrative Description of Trouble (How Malfunctioned)
22. Narrative Description of Repair Action (Action Taken)
23. Activity during which failed item discovered (When Discovered)
24. Effect of Failure (mission failure, performance degradation, no effect)
25. Total Parts Replaced
26. Total Operating Time (System or Equipment)
27. Operating Time-to-Failure (Equipment)
28. Operating Time Failed Item/Installed Item

*29. Failure Verified (Verified or denied by bench check)
*30. Type of Failure (primary or secondary)
*31. Analysis Required (Yes or No)
*32. Failure Analysis Report Number and Date
*33. Failure Cause-Failed Item (misapplication, overstress, vendor fault, etc.)

34. Delay Code
35. Downtime Code
36. Crew Size
37. Skill Level Maintenance Technician
38. Start Time for Maintenance
39. Stop Time for Maintenance

in the discussion below:

Data Elements 1,2: The intent of these elements is to provide a unique identifier for a failure incident and to provide for traceability of failure circumstance data which may extend over a period of time. Use of the Job Control Number does provide a means for tracing the failure data, but proper dating of various maintenance actions is sometimes ambiguous. Improvement can be made by a change in procedure.

Data Elements 3-16 (Except 13): These data elements are either directly provided on the reporting forms or can be obtained through use of the work unit code and technical manuals. Correct identification of the failed item (data elements 9-12) is the responsibility of the agency or group performing the analyses. These data elements also relate to the data elements (29-33).

Data Elements 17, 18, 13, 28: Use of these data elements are required under special circumstances when components have to be changed after a specified period of use (e.g., high power tubes or serially controlled items). Blocks 19-25 on the 349 form provide these data.

Data Elements 19-25: These data elements are directly provided for on either the AF Form 349 or 182. Narrative descriptions (data elements 22-23) are not normally processed into the data system. Collection of the raw data form must be done to obtain these data.

Data Elements 26,27: Operating time and time-to-failure information may be obtained by processing the outputs of the AFM 66-1 and

AFM 65-110 data jointly in a chronological manner. Maintaining operating time records beginning with the initial installation of the equipment in the field is required.

Data Elements 29-33: These data elements are essential to meeting reliability assessment objectives. The agency or group performing the analyses must supply and/or validate these data.

Data Elements 34-39: These data elements are required for maintainability assessments and are directly provided on existing data collection forms. Procedural changes and additional codes are required, however, so that the data can be used more effectively for maintainability analysis purposes.

PART/BOARD PREDICTED FAILURE RATES AND FIELD REPLACEMENT RATES

PART TYPE	QUANTITY	TOTAL PART HOURS x 10^6 (T)	TOTAL # OF REPLACEMENTS	OBSERVED PART REPL. RATE x 10^{-6}	PREDICTED FAILURE RATE x 10^{-6} (λp)	EXPECTED FAILURES (λpT)
MICROCIRCUITS						
Quad 2-input or gate 1700-2353	689	116.914	14	0.119	0.07	8.2
Quad 2-input or gate 1700-4722	79	13.405	0	-----	0.07	.94
Quad 2-input nand/nor 1700-2510	1124	190.728	49	0.257	0.07	13.4
J-K Flip-Flop and-or input 1700-2676	986	167.312	27	0.161	0.07	11.7
J-K Flip-Flop and Input 1700-2635	654	110.975	11	0.099	0.07	7.8
Dual 4-input nand/nor 1700-2312	177	30.035	3	0.099	0.07	2.1
Dual 2+Dual 3 input expand 1700-2551	287	48.700	1	0.021	0.07	3.4
Triple 3-input nand/nor 1700-2593	199	33.768	7	0.207	0.07	2.4
Dual driver high fan-out 1700-2478	943	160.015	13	0.081	0.07	11.2

PART TYPE	QUANTITY	TOTAL PART HOURS x 10^6 (T)	TOTAL # OF REPLACE-MENTS	OBSERVED PART REPL. RATE x 10^{-6}	PREDICTED FAILURE RATE x 10^{-6} (λp)	EXPECTED FAILURES (λpT)
Triple 2 inputs bus driver 1700-6537	43	7.296	0	-----	0.07	.5
Dual J-K Flip-Flop Com.Clock 1700-2718	439	74.493	7	0.094	0.07	5.2
Dual 2-input nand/nor 1700-2437	219	37.161	4	0.108	0.07	2.6
Single 8-input nand/nor 1700-2395	274	46.494	2	0.043	0.07	3.2
Operational Amplifier 1700-5174	6	1.018	0	-----	0.40	.41
Differential Comparator 1700-5216	13	2.206	0	-----	0.40	.88
Operational Amplifier 1700-5257	7	1.188	0	-----	0.40	.48
Dual 4-input line driver 1700-9366	19	3.224	0	-----	0.07	.23
Ladder Network 8 Bit Fixed Film 1700-6453	2	0.339	0	-----	0.07	.02
Ladder Network 11 Bit Fixed Film 1700-6479	2	0.339	0	-----	0.07	.02
Triple 2 input & single 3 input 1700-6495	85	14.423	1	0.069	0.07	1.01
8 input nand/nor gate 1702-9430	3	0.509	1	1.964	0.07	.04
TOTAL	6250	1060.542	140	0.132		75.7

PART TYPE	QUANTITY	TOTAL PART HOURS x 10^6 (T)	TOTAL # OF REPLACE-MENTS	OBSERVED PART REPL. RATE x 10^{-6}	PREDICTED FAILURE RATE x 10^{-6} (λp)	EXPECTED FAILURES (λpT)
CAPACITORS						
CK MIL-C-11015 1700-5745	4,216	715.402	1	0.0014	0.0158	11.3
CS	22	3.733	0	------	0.0158	0.5
CL MIL-C-3965 1707-1564	13	2.206	0	------	0.07	.15
CC (CC---) MIL-C-20	6	1.018	0	------	0.04	.04
CQ (CQ---) MIL-C-19978	33	5.599	0	------	0.02	.11
CSR (CSR 13) MIL-C-39003	146	24.774	0	------	0.05	1.2
CTM (CTM---) MIL-C-27287	39	6.618	0	------	0.0018	.01
CY (CY---) MIL-C-11272	3	0.509	0	------	0.06	.03
TOTAL	4478	759.859	1	0.00132	.017	12.9
RESISTORS						
RC (RC---) MIL-R-11	326	55.318	1	0.018	0.002	.11
RJ (RJ---) MIL-R-22097	20	3.395	1	0.295	1.000	3.4

PART TYPE	QUANTITY	TOTAL PART HOURS x 10^6 (T)	TOTAL # OF REPLACE-MENTS	OBSERVED PART REPL. RATE x 10^{-6}	PREDICTED FAILURE RATE x 10^{-6} (λp)	EXPECTED FAILURES (λpT)
1N5672A	2	0.339	0	-----	0.02	.007
TOTAL	647	109.785	3	0.027		2.2
<u>TRANSISTORS</u>						
JAN 2N682 SCR (Thyristor)	11	1.867	12	6.429	-----	-----
JAN 2N706 (NPN)	39	6.618	0	-----	0.10	.66
JAN 2N869A (PNP)	118	20.023	0	-----	0.15	3.0
JAN 2N1132 (PNP)	12	2.036	0	-----	0.15	.3
JAN 2N1613 (NPN)	73	12.387	9	0.727	0.10	1.23
JAN 2N2219A (NPN)	6	1.018	22	21.608	0.10	.10
JAN 2N2222A (NPN)	1185	201.079	19	0.095	0.10	20.12
JAN 2N2369A (NPN)	40	6.787	11	1.620	0.10	.68
JAN 2N2904A (PNP)	20	3.394	2	0.589	0.15	.51
JAN 2N2905 (PNP)	12	2.036	1	0.491	0.15	.31

PART TYPE	QUANTITY	TOTAL PART HOURS x 10^6 (T)	TOTAL # OF REPLACE-MENTS	OBSERVED PART REPL. RATE x 10^{-6}	PREDICTED FAILURE RATE x 10^{-6} (λp)	EXPECTED FAILURES (λpT)
JAN 1N759A (MIL-S-19500)	1	0.170	0	-----	0.02	.003
JAN 1N914 (MIL-S-19500)	47	7.975	0	-----	0.02	.16
JAN 1N935B (MIL-S-19500)	8	1.357	1	0.737	0.02	.03
JAN 1N965B (MIL-S-19500)	8	1.357	0	-----	0.02	.03
JAN 1N968B (MIL-S-19500)	1	0.170	0	-----	0.02	.003
JAN 1N1186 (MIL-S-19500)	6	1.018	0	-----	0.02	.02
JAN 1N1202A (MIL-S-19500)	44	7.466	0	-----	0.02	.15
JAN 1N3022B (MIL-S-19500)	1	0.170	0	-----	0.02	.003
JAN 1N3070 (MIL-S-19500)	2	0.339	0	-----	0.02	.007
USN 1N3595	55	9.333	0	-----	0.02	.19
JAN 1N3600 (MIL-S-19500)	239	40.555	0	-----	0.02	.81
JAN 1N3611 (MIL-C-19500)	5	0.848	0	-----	0.02	.02
1N4381	16	2.715	0	-----	0.02	.05

PART TYPE	QUANTITY	TOTAL PART HOURS x 10^6 (T)	TOTAL # OF REPLACE-MENTS	OBSERVED PART REPL. RATE x 10^{-6}	PREDICTED FAILURE RATE x 10^{-6} (λp)	EXPECTED FAILURES (λpT)
RL (RL---) MIL-R-22684	3371	572.016	2	0.004	0.072	41.19
RN (RN---) MIL-R-10509	177	30.035	1	0.033	0.006	.18
RW (RW---) MIL-R-26	47	7.975	0	-----	0.015	.12
RT (RT---) MIL-R-27208	27	4.582	0	-----	1.500	6.87
TOTAL	3968	673.320	5	0.007		51.9
DIODES						
JAN 1N202A (MIL-S-19500)	6	1.018	0	----	0.02	.02
JAN 1N645 (MIL-S-19500)	149	25.283	1	0.040	0.02	.5
JAN 1N746A (MIL-S-19500)	3	0.509	0	----	0.02	.01
JAN 1N751A (MIL-S-19500)	9	1.527	0	----	0.02	.03
JAN 1N752A (MIL-S-19500)	1	0.170	0	----	0.02	.003
JAN 1N753A (MIL-S-19500)	28	4.751	1	0.211	0.02	.1
JAN 1N758A (MIL-S-19500)	16	2.715	0	-----	0.02	.05

PART TYPE	QUANTITY	TOTAL PART HOURS x 10^6 (T)	TOTAL # OF REPLACE-MENTS	OBSERVED PART REPL. RATE x 10^{-6}	PREDICTED FAILURE RATE x 10^{-6} (λp)	EXPECTED FAILURES (λpT)
JAN 2N2905A (PNP)	26	4.412	2	0.453	0.15	.66
JAN 2N2907 (PNP)	32	5.430	2	0.368	0.15	.81
JAN 2N2945A (PNP)	94	15.951	0	-----	0.15	2.39
JAN 2N3055 (NPN)	4	0.679	5	7.366	0.10	.07
2N3495 (PNP)	6	1.018	4	3.929	0.15	.15
JAN 2N3506 (NPN)	18	3.054	7	2.292	0.10	.31
S22687	102	17.308	0	-----	-----	-----
HY386-40	29	4.921	0	-----	-----	-----
2N3790 (PNP)	4	0.679	0	-----	0.15	.10
2N1910W SCR Thyristor	1	0.170	1	5.893	-----	-----
TOTAL	1832	310.867	97	0.312	-----	------
ADJUSTED TOTALS	1689	286.601	84			31.4

BOARD TYPE	QUANTITY	TOTAL BOARD HOURS $\times 10^6$ (T)	TOTAL # OF REPLACEMENTS	OBSERVED BOARD REPL. RATE $\times 10^{-6}$	PREDICTED FAILURE RATE $\times 10^{-6}$ (λp)	EXPECTED FAILURES (λpT)
LOGIC BOARDS						
ADD (1700-2064)	6	1.018	3	2.947	2.370	2.4
BU (1700-2189)	63	10.690	20	1.871	1.295	13.8
C23 (1700-1983)	12	2.036	1	0.491	1.295	2.64
C27 (1700-2023)	48	8.145	5	0.613	1.123	9.1
CMP (1700-2007)	19	3.224	3	0.930	1.724	5.56
CTR (1700-2031)	17	2.885	5	1.733	1.988	5.73
CUD (1700-2015)	13	2.206	2	0.907	2.370	5.23
DEC (1700-2049)	2	0.339	1	2.950	2.300	.78
EDT (1700-2072)	3	0.509	2	3.292	2.074	1.05
F21 (1700-2122)	65	11.030	18	1.632	1.123	12.39
FGM (1706-5756)	8	1.357	0	-----	1.123	1.5
G2A (1700-2163)	27	4.582	6	1.309	0.983	4.5
G21 (1700-2130)	63	10.690	6	0.561	0.843	9.01
G22 (1700-2148)	43	7.297	8	1.096	0.913	6.66
GAI (1700-1991)	65	11.030	11	0.997	0.843	9.29
GBI (1700-2155)	38	6.448	8	1.241	1.053	6.78
INV (1700-2171)	69	11.708	34	2.904	0.913	10.69
REG (1700-2080)	10	1.697	3	1.768	2.370	4.02
SRC (1700-2098)	19	3.224	8	2.481	2.370	7.64

BOARD TYPE	QUANTITY	TOTAL BOARD HOURS $\times 10^6$ (T)	TOTAL # OF REPLACE-MENTS	OBSERVED BOARD REPL. RATE $\times 10^{-6}$	PREDICTED FAILURE RATE $\times 10^{-6}$ (λp)	EXPECTED FAILURES (λpT)
SRL (1700-2106)	11	1.867	6	3.214	2.214	4.13
SRS (1700-2114)	16	2.715	10	3.683	2.230	6.05
TOTAL	617	104.697	160	1.528		128.86
HYBRID BOARDS						
RAM (1701-0513)	2	0.339	6	17.670	4.795	1.62
BO (1701-0588)	1	0.170	4	23.529	2.250	.38
BQ1 (1700-6743)	1	0.170	3	17.647	4.175	.709
BQ2 (1700-6750)	1	0.170	0	------	5.856	.99
DAR (1700-6768)	1	0.170	1	5.882	2.970	.50
DAS (1700-5885)	2	0.339	0	------	9.882	3.34
DC2 (1700-6107)	2	0.339	0	------	7.988	2.71
DM (1701-0877)	1	0.170	1	5.882	4.440	.75
EG (1701-0455)	2	0.339	2	5.900	6.108	2.07
HQ (1700-6099)	1	0.170	14	82.353	9.577	1.62
IND (1717-7271)	26	4.412	7	1.587	-----	-----
LPD (1700-6248)	8	1.357	1	0.737	5.384	7.3
PD (1706-5426)	35	5.939	0	-----	0.500	2.97
PD1 (1706-5442)	10	1.697	0	-----	2.084	3.54
PD2 (1706-5368)	9	1.527	0	-----	3.668	5.60
RA (1700-6057)	2	0.339	1	2.950	5.419	1.83

BOARD TYPE	QUANTITY	TOTAL BOARD HOURS $\times 10^6$ (T)	TOTAL # OF REPLACE-MENTS	OBSERVED BOARD REPL. RATE $\times 10^{-6}$	PREDICTED FAILURE RATE $\times 10^{-6}$ (λp)	EXPECTED FAILURES (λpT)
RB (1701-0620)	16	2.715	2	0.737	1.302	3.53
RD1 (1701-0471)	6	1.018	2	1.965	3.179	3.23
RD2 (1700-6792)	4	0.679	3	4.418	5.271	3.57
RD3 (1701-0497)	6	1.018	3	2.947	8.308	8.46
RO (1702-5917)	3	0.509	3	5.894	2.685	1.36
SQ (1700-6826)	2	0.339	6	17.699	7.778	2.64
ST (1700-9333)	8	1.357	0	-----	3.828	5.19
out of 126 on-line SW (1716-7149)	14	2.376	6	2.525	-----	-----
VD (1706-5335)	9	1.527	0	-----	0.500	.76
WS (1706-5277)	19	3.224	0	-----	0.788	2.54
TOTAL	191	32.409	65	2.006		
ADJUSTED TOTAL	151	24.62	52			67.2